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REVIEW OF THE ENGINEERING ASPECTS OF POWER PLANT DISCHARGES

HYDRONAUTICS, INCORPORATED

PREPARED FOR
MARYLAND DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION AGENCY

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By

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7210 Pindell School Road
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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Monitoring
Washington, D. C. 20460

and

Power Plant Siting Program
MARYLAND STATE DEPARTMENT OF NATURAL RESOURCES
Annapolis, Maryland 21401

ABSTRACT

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The present study was carried out in the Environmental Science and Anti-pollution Systems Department of HYDRONAUTICS, Incorporated under the joint sponsorship of the Environmental Protection Agency and the Power Plant Siting Program, Maryland State Department of Natural Resources. The study was initiated recognizing that a need existed for a detailed data base on the factors influencing steam-electric power plant effluent discharges and relevant control technology. The recently enacted Power Plant Siting legislation in the State of Maryland provided a unique opportunity for acquiring such a data base. Early interest in, and support for, the program came from Messrs. William Lacy and George Rey of the Environmental Protection Agency and Mr. Lee Zeni of the Power Plant Siting Program.

Technical monitoring for the program was provided by Mr. Alden Christianson of the Environmental Protection Agency and by Dr. Myron Miller of the Power Plant Siting Program. Dr. Miller provided valuable insights into the trade-offs involved, in terms of environmental impact, among the various possible cooling techniques and provided relevant information on the other studies being conducted under the Power Plant Siting Program. Valuable suggestions on the nature and scope of the study were also provided by Mr. George Manning and Dr. Bruce Tichenor of the Environmental Protection Agency.

The heart of the present study is a detailed inventory of power plant characteristics obtained from utilities within the State of Maryland. The study would never have been possible without the excellent cooperation displayed by the power plant personnel involved. They reviewed our initial questionnaire, discussed freely with us all the relevant factors during our visits to the power plants and examined our completed data sheets. In this regard, our special thanks go to Messrs. P. Benziger and H. Crim of PEPCO, D. Cobbs, C. G. McVay and R. Hodges of APSCO, J. Hammons, T. Roe and D. Winslow of DELMARVA, and W. Witte and M. Malone of BG&E.

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PART I

SECTION I

SUMMARY AND CONCLUSIONS

Control measures for minimizing the environmental impact of power plant effluents must take into account a number of diverse factors. Specifically, for effective control it is necessary to delineate the power plant operating practices that govern the characteristics of the effluents and the changes (due primarily to nonenvironmental reasons) that have occurred in recent years in these practices.

The present report discusses the various engineering aspects involved in control of waste effluent discharges from steam electric power plants, utilizing as examples certain selected power plants within the Maryland region. A comprehensive review is given of the current operating and control practices at the various plants, including any problems encountered. The detailed information gathered concerns not only thermal discharges but also the wastes resulting from chemical additions to the boiler and cooling water systems as well as the ash-laden waste waters from stack cleaning.

The information gathered is then used as the basis for making engineering assessments of current control practices as well as of the improvements required in the state-of-the-art of the control technology in order to cope with present and projected effluent standards.

Based on an analysis of the information collected, the following specific conclusions are drawn:

1. Even though all the power plants surveyed are fossil-fueled and most of them use once-through cooling, the plants are representative of their general type in the entire country. For example, the annual rate of increase in efficiency for the newly constructed plants included in our survey is compatible with the corresponding national value. The present average efficiency of power generation in the Maryland region is 34.2%.

2. Newer, larger power plants have smaller temperature rises across the condensers than older, smaller plants. However, the average rate of water use is approximately the same for all plants and is about 1.5 CFS per MW of installed power plant capacity.

3. While a number of chemicals are used in once-through cooling systems, chlorine is by far the most abundantly used chemical. No uniform procedures are followed during chlorination; dosage appears to be approximately dependent on cooling-flow rate as well as water quality. There are no definitive trends in the use of other chemicals.

4. Chemicals, such as caustic soda and hydrazine, are added to boiler make-up water. Boiler blowdown is usually discharged after water recovery, untreated into the environment since, even with the added chemicals, it is usually purer than the source water.

5. The amount of ash generated by the fossil-fueled plants depends on the ash content of the fuel used, but this figure appears to be about 317 tons per year per MW of plant capacity for all-coal operation and about one-tenth of a ton per year per MW for all-oil operation. All power plants surveyed attempt to remove fly ash from stack gases; removal efficiencies were as high as 99.5%. All the power plants surveyed have ash settling ponds where the waste ash is settled out from the waste water prior to discharge.

6. For fossil-fueled plants, the installed cost of once-through cooling systems including the costs for site preparation for inlet and discharge, piping, other materials and labor (but excluding the condenser), is about $4 to $7 per KW (1972 dollars), and decreases with increasing plant size. The total cost of operation and maintenance of the systems, including costs of chemical addition, is about one mill per thousand gallons of cooling flow, and decreases with increasing cooling flow.

7. The total cost of operation and maintenance of boiler-water treatment systems is about 10 cents per year per KW of power plant capacity.

8. The total cost of collecting and disposing bottom and fly ash is between 5 and 20 dollars per ton. The cost per ton for the collection of fly ash is dependent on the ash content of the fuel as well as the efficiency of the precipitator, decreasing somewhat with increasing values of the former and increasing sharply with increasing values of the latter.

SECTION II

RECOMMENDATIONS

Based on the findings of the present study, the following recommendations are made:

1. While several engineering and economic studies have been carried out on possible modifications of once-through cooling systems, these studies have generally been of limited scope or dealt with power plants in specific regions. Therefore, detailed engineering and economic assessments should be carried out on possible modifications of once-through cooling systems in the Maryland region, and on backfitting these power plants presently using once-through cooling with closed-cycle cooling systems for minimizing environmental impact. Since the factors influencing the selection of a cooling system modification will be site specific, these engineering and economic assessments should be made taking the "building block" approach where representative components of possible system modifications are selected and evaluated.

2. We believe that it is essential to develop a more rational basis for defining the environmental impact of thermal effluents, since parameters such as the temperature increase and total waste heat discharges are by themselves inadequate indicators. For a comprehensive characterization of environmental impact, one or more parameters should be developed comprising the amount of water used, the increase above the background of temperature as well as chemical concentration, and the time during which the increase is maintained. This is especially the case when considering modifications or backfitting the cooling systems of plants currently using once-through cooling systems.

3. Critical engineering and economic assessments of the possible constructive uses of waste heat and of the integration of various water uses should be carried out. One possibility that seems to hold considerable promise is that of coordinating sewage-treatment and power-generation systems, the so-called "el-wa-sew" concept. Assessments of such systems should be made using a "building block" approach, since various factors influencing system compatibility are likely to be site specific. Potential power plant sites in Maryland suitable for "el-wa-sew" application should be identified.

SECTION III

INTRODUCTION

III.1 GENERAL REMARKS

An ecological problem that has become of increasing concern in recent years is the possible adverse consequences of power plant thermal discharges into water bodies. Since modern steam electric generating power plants utilize large amounts of water for cooling purposes, the demand for water is closely related to the demand for power. Thus, as the demand for power increases in the future, so too will the demand for water.

Present fossil-fueled power plants require about 10,000 BTU's to generate one KWH of electricity, while light-water nuclear power plants require about 13,000 BTU's for the generation of the same KWH of electricity[1]. Since the thermal equivalent of 1 KWH of electricity is only 3413 BTU's the remaining heat (about 6500 BTU's for a fossil-fueled plant and 10,000 BTU's for a nuclear plant) must be considered as waste heat.

Power plant efficiency is, of course, the principal factor that determines the amount of heat required for unit-power generation and, correspondingly, the resulting amount of waste heat. The following are presently the best plant efficiencies[2] for different categories of power plants:

Nuclear Light Water	30-34%
Fossil Fueled (Rankine Cycle)	38-42%
Nuclear LMFBR* or HTGR+	40-45%
Brayton (Gas Regenerative)	34-35%

In the future, the major source of waste heat will be from power generation by nuclear power plants. As indicated above, a nuclear power plant generates about 150% as much waste heat as a conventional fossil-fueled power plant. In 1970, 1.2% of all electrical power generated came from a nuclear source. In 1990, this figure is projected to be 40%, and by the year 2020, 80% of all power generated will come from a nuclear source (References 3, 4). With this projected increase in

*LMFBR = Liquid Metal Fast Breeder Reactor
+HTGR = High Temperature, Gas Cooled Reactor

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nuclear generated power, the amount of waste heat to be dissipated will increase significantly. Figure 1 represents the projected power needs and resulting waste heat generation in the United States during the next fifty years (see References 3, 5-11)* It should be noted however, that if the power plant efficiencies for the different plant categories mentioned above follow the improved efficiency trend (References 12, 13) experienced by fossil-fueled plants during the past 50 years (see Figure 2), then the total amount of waste heat generated will be less than that shown on Figure 1.

Since for heat-transfer purposes water is 4.5 times as effective as air by weight and 42 times as effective by volume (Reference 8), it is the most commonly used medium for dissipating power plant waste heat. With the increase in power demands, and the resulting increase in the amount of waste heat generated, the amount of water required for cooling purposes will increase significantly. The actual amount of water required will, of course, depend on the specific cooling methods employed and the detailed characteristics of these methods. Thus, for a given amount of heat to be rejected, the amount of water used will be inversely proportional to the temperature rise across the cooling condensers. Similarly, if a cooling tower is used, the amount of make-up water required will be dependent on such factors as drift losses, the number of recirculations before blowdown and the evaporation rate.

In the past, most studies dealing with power plant thermal discharges have been primarily devoted to predicting the physical and biological impacts of these discharges on the receiving water body[12,14,15,16]. Specifically, relatively little attention has been given to various control techniques and the trade-offs involved therein, though a burgeoning literature of these subjects is becoming increasingly more evident. It should be noted that in thermal-pollution abatement, as in other real-life pollution abatement problems, the benefit to be attained from a specific control technique must be weighed against the economic, social and aesthetic factors involved.

The objective of the present study is to review the various factors involved in the control of waste-effluent discharges from steam-electric power plants, utilizing as examples the power plants within the Maryland region. (The Maryland region is being defined here to mean the State of Maryland and the adjacent areas along the western boundary of the state.) A detailed discussion of the scope of the present study and a specific listing of its objectives are given in Section III.2. However, it should be noted here that the impact of the discharge of waste-effluents into a waterbody, and hence the appropriate control strategies, can be viewed in terms of three more or less distinctive and consecutive phases. The first phase, which can be termed the source phase, is concerned with the various factors

*These estimates are "pre-energy crisis" projections.

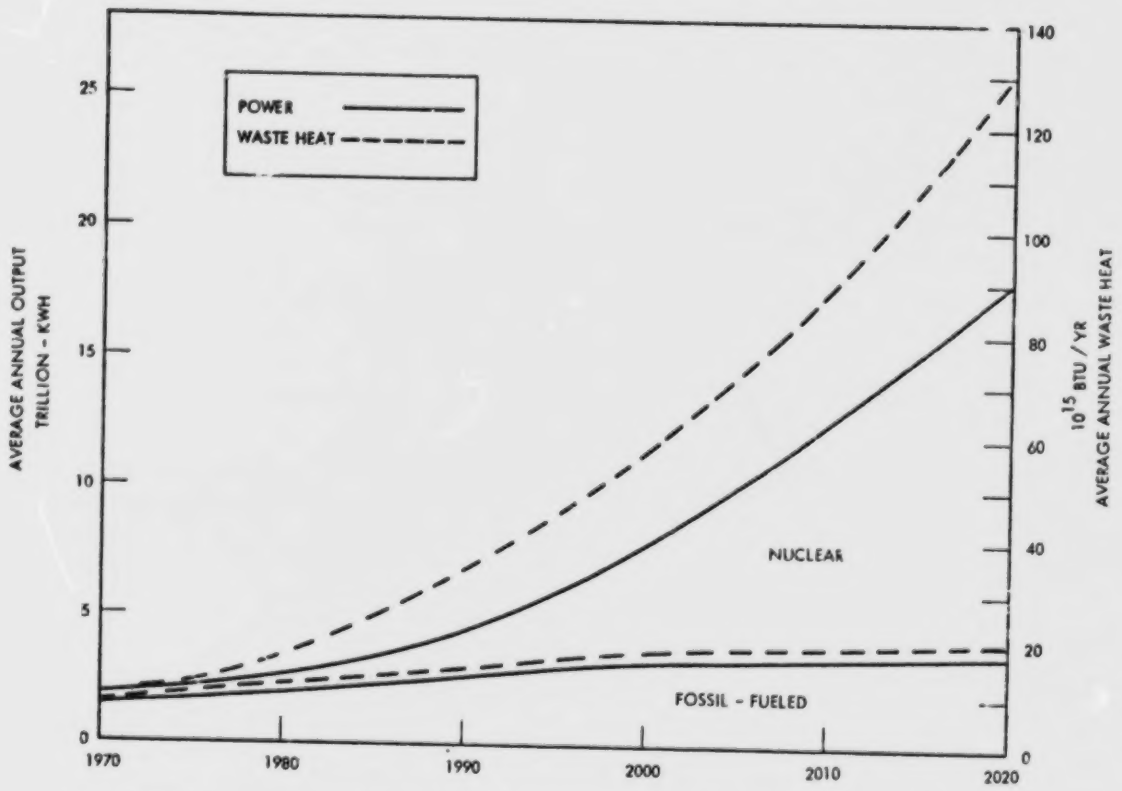


FIGURE 1 - PROJECTED POWER REQUIREMENTS IN THE UNITED STATES
(PRE-ENERGY CRISIS PREDICTIONS)

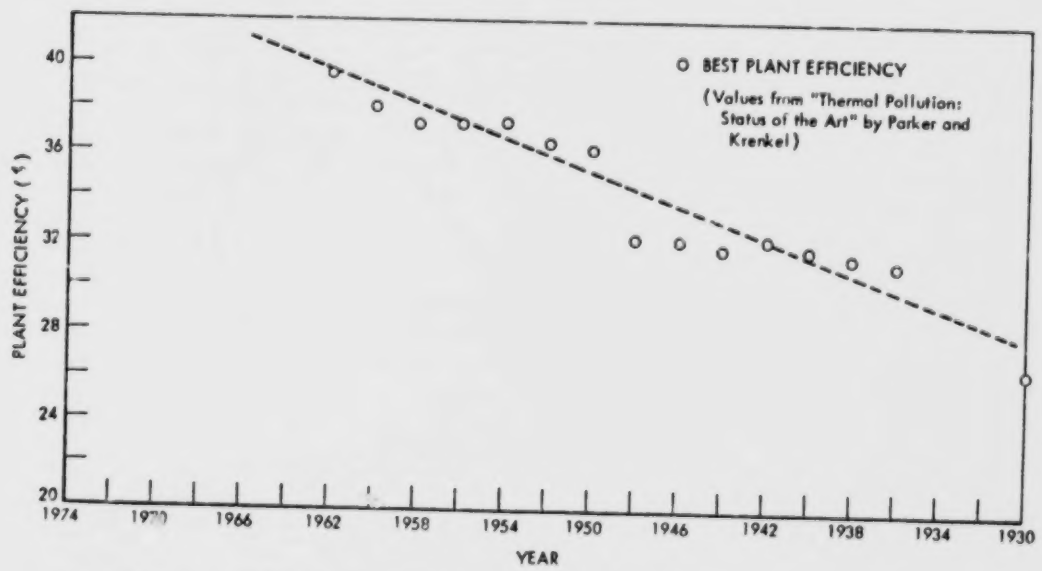


FIGURE 2 - BEST PLANT EFFICIENCY IN CONTINENTAL UNITED STATES

influencing the characteristics of the effluents and the various trade-offs involved in controlling the discharge of the effluents. The second phase, which can be termed the dispersion phase, is involved with the factors influencing the dispersion of the effluents into the aquatic environment. The third phase, which can be termed the contact phase, is concerned with the impact of the effluents themselves, as well as the changes induced by them, on the aquatic biological community.

The major point to note here is that each of the phases described above has associated with it different classes of control strategies. Thus, when it is required to dissipate a given amount of waste heat into the environment, the control measure may involve the construction of cooling ponds, spray systems, mechanical-draft or natural-draft cooling towers, or even closed cycle "dry" cooling towers. When once-through cooling is employed, the control measure may involve the reduction in discharge temperature by an increase in the amount of circulating water*. However, when the local temperature increase, due to the discharge, is of primary concern, the control measures may also be instituted in the dispersion phase by such techniques as the artificial promotion of turbulent mixing in the vicinity of the outfall or by the construction of submerged outfalls with multiport diffusers. Control measures are also possible during the "contact phase" by locating the outfalls and their zones of influence away from vital aquatic areas (such as oyster beds).

The present study is concerned only with a characterization of the source phase, and the control technology relevant thereof. However, it is our view that it is erroneous to consider all thermal discharges as being necessarily harmful to the aquatic environment and to seek their unconditional elimination. It should be noted that at least under certain conditions, thermal discharges may have a beneficial impact on the receiving waters. On the other hand, constructive use of the discharges necessarily implies proper waste-heat management, and a thorough understanding of the various factors influencing such management is presently lacking.

Much work remains to be done not only on waste-heat management alternatives but also on identifying the differences in environmental impact when various control techniques are employed. Often a control technique designed to minimize aquatic thermal impact may lead to other adverse environmental impacts. Thus the use of evaporative cooling towers to minimize thermal discharges can lead to more consumptive water use and more chemical load (in the blowdown) than in once-through

*On the other hand, an increase in the amount of circulating water will increase the problem of "thermal shock" associated with the ingestion of aquatic organisms into the condenser cooling water. A more detailed discussion of this aspect will be given in Section VI.

cooling. Again, when cooling towers are operated in an estuarine environment, problems of the disposal of concentrated brine and salt deposition from brackish-water drift loss will also have to be tackled. Moreover, cooling towers will also reduce the overall efficiency of the power plant

The point to note here is that to assess the trade-offs involved in various possible control strategies for minimizing the environmental impact of power plants, information on a wide variety of engineering aspects of cooling are required It should be emphasized that in many cases the choice of a specific cooling technique may be dictated by nonenvironmental considerations. For example, in some parts of the country, such as the Southwest, the demand for cooling water exceeds available supply, so that the cooling method has to be chosen so as to fit the latter.

III.2 SCOPE OF THE STUDY

As mentioned earlier, the primary objective of the present study was to review the various engineering aspects involved in the control of waste effluent discharges from steam electric power plants. Specifically the objectives were to assess the heat rejection effectiveness of different cooling systems, chemical treatment effectiveness, economic considerations that influence cooling method selection and operation, and auxiliary systems that may contribute to water pollution.

At the outset of the study it was concluded that the objectives would be accomplished best by a comprehensive review of specific power plants in terms of the various problems encountered and the current control practices. The information gathered can then be used as the basis for making engineering assessments of current control practices as well as improvements required in the state-of-the-art.

Since the detailed investigation of even a selected number of power plants on a nationwide basis is outside the scope of the present study, attention was confined to power plants located within the State of Maryland. The area selected for study is located within the Chesapeake Bay Water Resource Region (see Figure 3). Figures 4 and 5 represent the projected power generation and water use within this water-resource region for the next fifty years (Reference 3). Note that in Figure 5 curves are given for the projected cooling-water use both for the case when all of the waste heat is dissipated by once-through cooling and for the case when wet cooling towers are employed. A more detailed discussion of the projections will be deferred until later.

Under a newly enacted law, the Maryland Power Plant Siting Program is currently conducting a very comprehensive study of the air and water quality effects of power plants utilizing once-through cooling as well

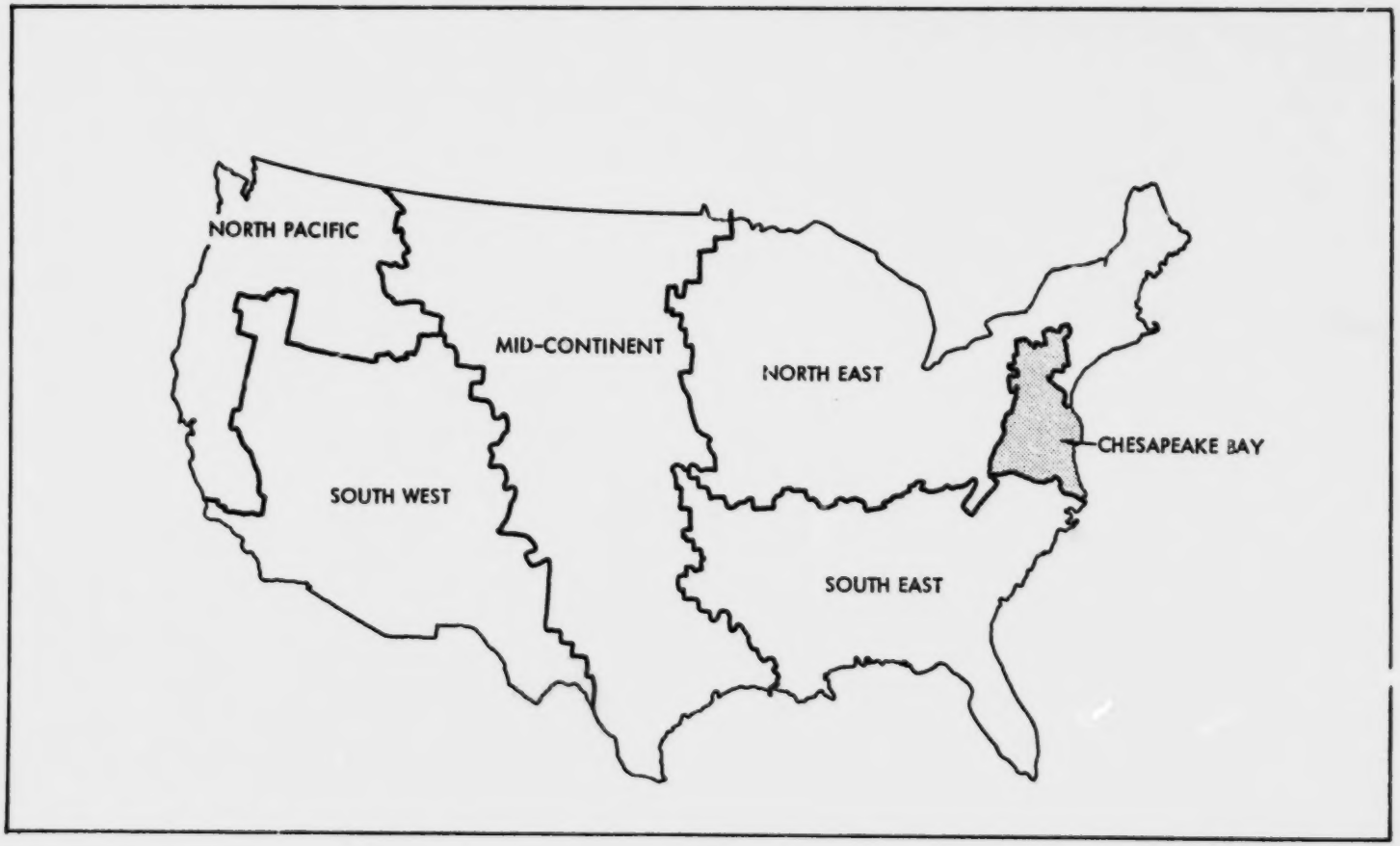


FIGURE 3 - WATER RESOURCE REGIONS

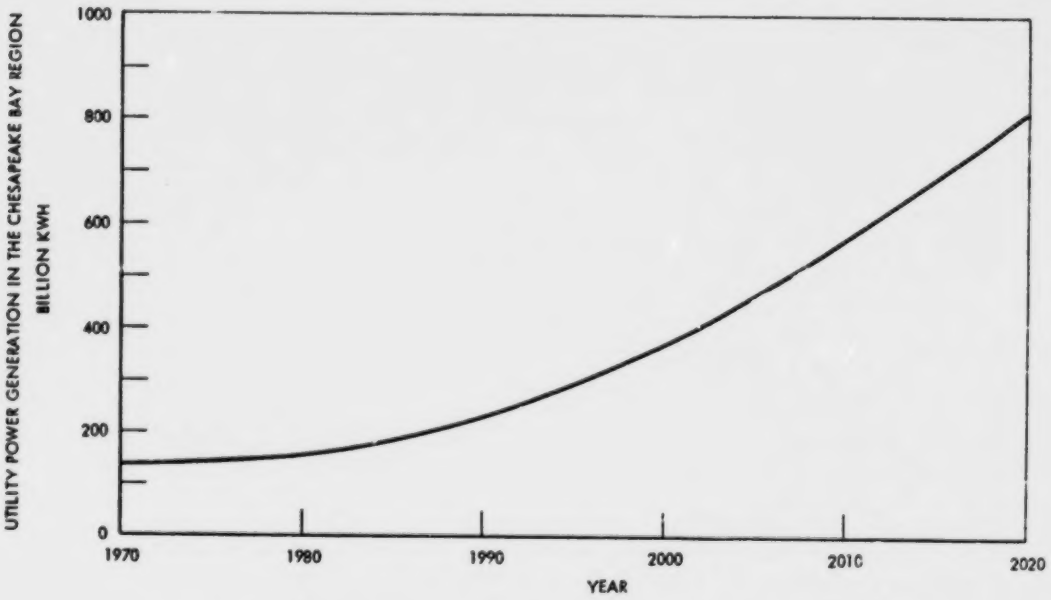


FIGURE 4 - PROJECTED POWER GENERATION IN THE CHESAPEAKE BAY REGION (PRE-ENERGY CRISIS PREDICTIONS)

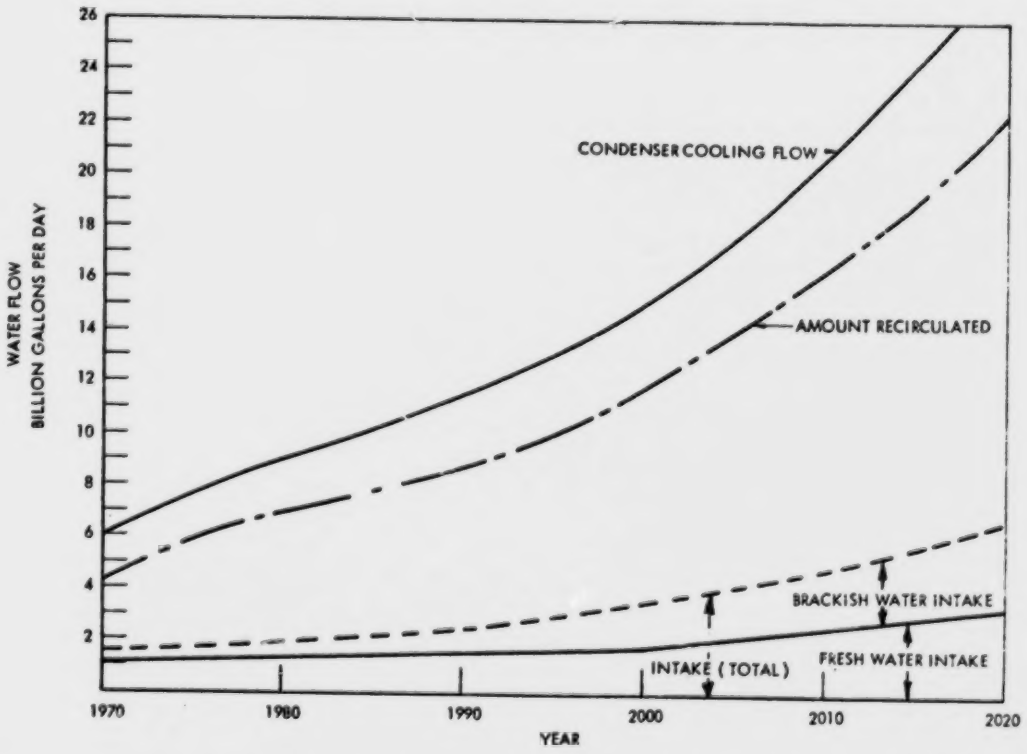


FIGURE 5 - PROJECTED WATER USE IN THE CHESAPEAKE BAY REGION (PRE-ENERGY CRISIS PREDICTIONS)

as cooling towers. Some of the data being acquired in the above program are of direct relevance to the present study, and the availability of this data was a strong factor in our decision to focus our investigations on the power plants located within Maryland. At the same time it was felt that the conclusion drawn from the study could be readily extended to a nationwide scale since Maryland has a wide variety of power plants discharging into different aquatic environments. Thus the existing and proposed plants include the nuclear-powered type as well as conventional, fossil-fueled type discharging into harbor, estuarine and riverine receiving environments.

The work that has been performed in the present study has been accomplished in terms of three separate tasks. Since the description given in the report will follow this threefold division, it is relevant here to set forth in detail the initial objectives of these tasks.

The objective of the first task was to inventory and characterize the existing power plants within the State, especially with respect to their thermal loads, cooling water requirements, chemical loads and ash-handling systems. At an early stage in the program it was concluded that this task had to be accomplished not only through the use of existing data, such as those from the Power Plant Siting Program and the Federal Power Commission, but also by a direct survey tailored to the specific requirements of the present study. Toward this end, a fairly comprehensive questionnaire was developed and distributed to selected power plants within the State. The results of the survey, as well as the questionnaire itself, are discussed in detail in Section IV of the present report.

The second task was concerned with an assessment, utilizing the data gathered under the first task, of the engineering, economic and practical aspects of existing effluent control and treatment systems. The objective here was also to compare the control practices in use with the "best available" state-of-the-art.

The objective of the third task was to assess the improvements required in the state-of-the-art of the control technology in order to cope with present and projected effluent standards as well as the expected rise in effluent quantities.

The accomplishments and conclusions from the above three tasks are discussed, respectively, in Sections IV, V, and VI of the present report.

SECTION IV

INVENTORY OF THE CHARACTERISTICS OF

POWER PLANTS WITHIN MARYLAND

IV.1 POWER PLANT QUESTIONNAIRE

As mentioned before, at an early stage in the present study it became apparent that the objectives set forth earlier could not be accomplished utilizing existing data sources alone, and that a comprehensive survey tailored to the specific requirements of the present study will be required. Toward this end a detailed questionnaire was developed for use as a basis for gathering the required information. In preparation for the questionnaire, a review of current literature on the subject of power plant cooling methods, chemical treatment of cooling systems, and economic considerations was undertaken. The questionnaire was not specifically designed for a particular cooling method but was, rather, designed in such a way as to provide the maximum possible information from power plants employing a variety of cooling methods.

The questionnaire, (see Appendix A) containing a total of 226 questions, was divided into seven sections, each of which represented a different area of interest. The areas covered were general background, cooling techniques, chemical treatment of water used, disposal of wastes (such as fly ash) from noncooling sources and general economic as well as engineering factors. Thus, as will be evident from an examination of the questionnaire, it was designed to gather information not only on thermal discharges and cooling systems, but also on a variety of auxiliary systems.

The procedure used in gathering the data was as follows. The questionnaire was sent to a selected number of utilities, after the initial contacts had been made, and after the utilities concerned had expressed their willingness to cooperate in the survey (see Table 1). The utilities were given an opportunity to review the questionnaire, and then they were visited by HYDRONAUTICS' personnel for detailed discussions on the various aspects of the information requested. Upon completion of the visits, the collected data were compiled on a specially prepared "Power Plant Information Sheet" (see Appendix B) and cross checked against data from other sources (see below). The draft of this "Power Plant Information Sheet" was then sent to the utilities for their review, so that they could indicate the changes they felt should be made.

Prior to the distribution of the questionnaire, it was decided to impose two requirements on the power plants surveyed:

1. The power plant must be steam-electric, utilizing a cooling water system. (This requirement eliminated gas-turbine and hydroelectric power plants.)

2. The plant capacity must be greater than 100 MW.

Power plants, whose capacities were less than 100 MW, were not included in this study for the following reasons:

1. There was an insufficient number of plants to make comparisons.

2. Operational procedures for small plants differed from those of large plants.

3. Insufficient information was available for verification of data.

Table 2 indicates the results of the "Power Plant Information Survey" distributed to the ten participating power plants. This table represents the distribution of questions, the average percentage of questions not applicable, and the percentage of applicable questions answered in each section. The highest percentage of completed questions (91%), occurred in Section 1, the section containing questions on the background statistics of the power plant. The poorest response (17.8%) occurred in Section 3, the section containing questions on the chemical analysis of make-up, blowdown, corrosion-inhibitors, and anti-foulants. The overall results of the power plant survey were excellent and provided most of the information that was originally sought.

Originally it had been our intention to distribute the "Power Plant Data Sheet" to selected power plants located in Maryland, Washington, D. C , and along the Virginia shore of the Potomac River. The cooperation displayed by the Maryland utilities and power plant personnel during the visits exceeded that which we had expected. We found, however, that our intention to include power plants located in Washington, D. C. and along the Virginia shore of the Potomac River, was hindered by the less cooperative attitude of the operating utilities. Hence, data we have obtained on these plants from other sources have not been verified; thus, in the analysis phase, these data were used with caution.

IV.2 DATA FROM OTHER SOURCES

In addition to the data acquired through the questionnaire, some data have also been acquired through other sources, both for purposes of verification and for filling in the gaps in the former data. Some relevant information was available through the studies being conducted as a part of the Maryland Power Plant Siting Program. Much information

TABLE 1

Utilities Contracted During Early Stages of the Survey

APSCO	Allegheny Power Service Corporation
BG&E	Baltimore Gas and Electric Company
DELMARVA	Delmarva Power and Light Company
PEPCO	Potomac Electric Power Company
VEPCO	Virginia Electric Power Company

TABLE 2

Questionnaire Statistics

Section	Number of Question	% of Question Not Applicable to Plants Surveyed	% of Applicable Questions Answered
1	11	0	91.0
2	44	38.8	56.4
3	110	24.1	17.8
4	13	0	34.6
5	20	63.0	78.3
6	10	0	48.0
7	18	16.6	29.3

has also been obtained from the Federal Power Commission annual reports. These reports, required to be submitted by power plants to the Federal Power Commission, provided a good source of preliminary information, but did not cover the various areas of interest extensively enough for a thorough evaluation. Additional preliminary data have been obtained from Dr. Loren Jensen of Johns Hopkins University. Dr. Jensen was kind enough to provide us with an opportunity to review some as yet unpublished data that he has accumulated.

Unverified information from the above-mentioned sources was used as the data base for those plants that would not cooperate in the survey. This data has been included in Section B of the "Power Plant Information Sheet". In the analysis phase of this study; this unverified information has been used only when it correlated reasonably well with other verified information.

IV.3 GENERAL INFORMATION AND PRESENTATION OF DATA

The data obtained from all sources have been compiled into different categories and are presented in the form of histograms, since these are best suited for the comparison of quantitative information of the type of concern here.

An examination of the distribution of power plant generating capacity for all (including gas-turbine and hydroelectric) power plants located within Maryland indicates that, in the past, the installed capacity of newly-constructed plants tended to be generally in the range of less than 500 MW (see Figure 6). This trend has changed in the past 10 years, however, with the installed capacity of the more recently constructed power plants being in the range of greater than 500 MW (e.g., Morgantown - 1309 MW, commenced operation in 1970; Chalk Point - 730 MW, commenced operation in 1964). Indeed, a survey of available information on power plants which are either proposed or are presently under construction within Maryland shows that these plants will have installed capacities of greater than 1000 MW (Reference 17).

A brief profile of the fossil-fueled power plants operating within the State of Maryland is presented in Table 3. This table summarizes pertinent information such as location, installed capacity and energy source. Of the fifteen power plants listed in Table 3, only ten have been selected for detailed study; the other five power plants failed to meet the requirements of this study (see p. 13). Table 3 also lists a similar brief profile of power plants included in this study, but are located outside the State of Maryland. Figure 7 shows the location of the power plants included in this study.

The mean generating capacities for these fossil-fueled plants is 521 MW, with the majority of the plants distributed in the 100-800 MW capacity range (see Figure 8). The average age of the power plants is 30.9 years,

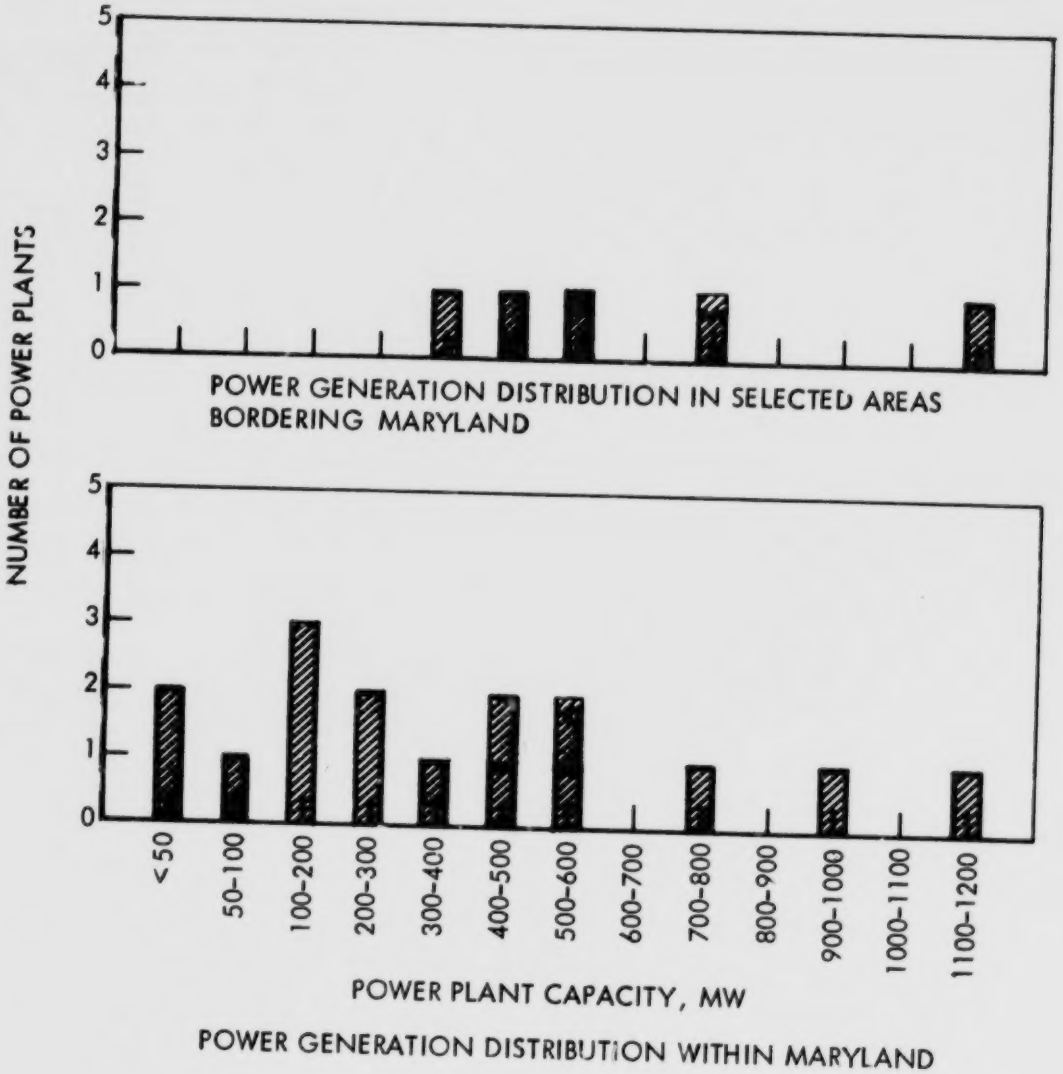


FIGURE 6 - POWER GENERATION DISTRIBUTION BY ALL METHODS WITHIN MARYLAND AND THE MARYLAND REGION

TABLE 3
Power Plants Operating Within Maryland
and Within the Maryland Region

Utility	Plant	Location	Installed Capacity MW	Type*
Power Plants Operating in Maryland				
Baltimore Gas and Electric Co. (BG & E)	Westport	Baltimore	194	F
			132	G
	Gould St.	Baltimore	156	F
	Riverside	Baltimore	322	F
			182	G
	Wagner, H.A.	Baltimore	992	F
			16	G
	C. P. Crane	Baltimore	386	F
			16	G
Delmarva Power and Light Co. of Md. (DELMARVA)	Vienna	Vienna	244.5	F
			18.6	G
The Potomac Edison Co. (Allegheny Power Serv. Corp.) (APSCO)	Smith, R. P.	Williamsport	129	F
Potomac Electric Power Co. (PEPCO)	Dickerson	Dickerson	570	F
	Chalk Point	Aquasco	730	F
	Morgantown	Newburg	1309	F
Power Plants Operating in the Maryland Region				
Potomac Electric Power Co. (PEPCO)	Potomac River	Alexandria, Virginia	515	F
	Benning Road	Wash. D. C.	712	F
	Buzzard Point	Wash. D. C.	305	F
			249	G
Virginia Electric and Power Company (VEPCO)	Mount Storm	Mount Storm, W. Va	1106	F
			14.9	G
	Possum Point	Dumfries, Va.	477.1	F
			91.2	G

* F = Fossil Fuel Operation
G = Gas Turbine

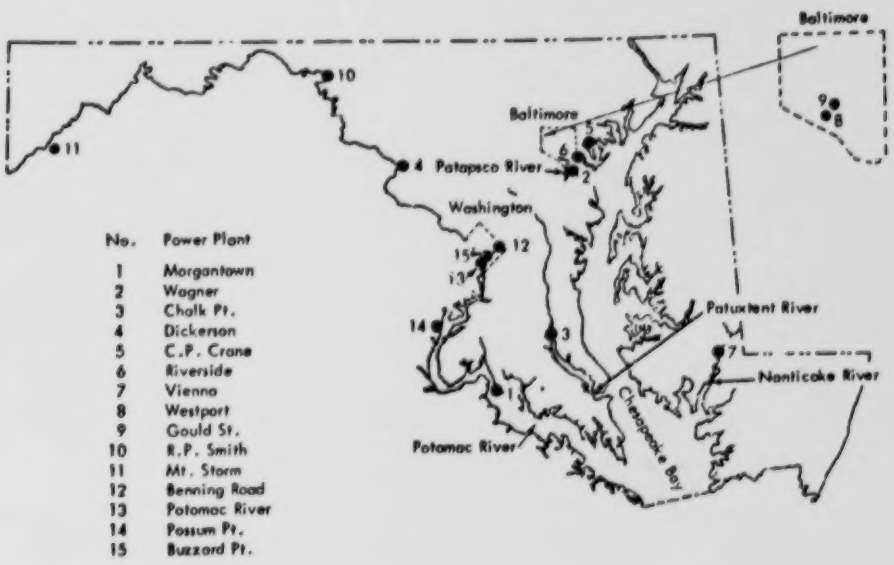


FIGURE 7 - POWER PLANT LOCATION

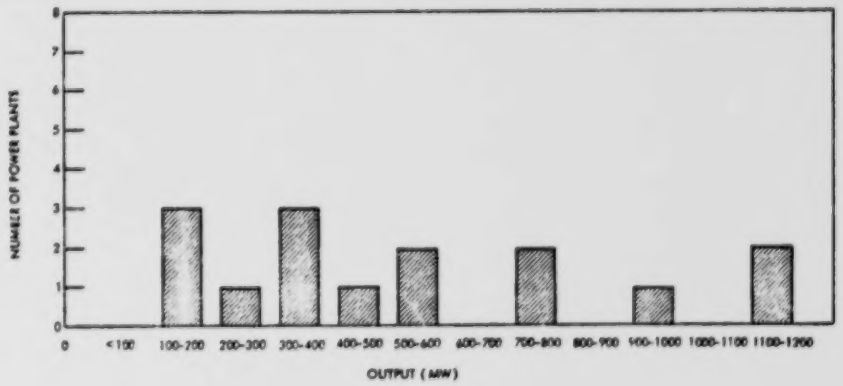


FIGURE 8 - POWER PLANT DISTRIBUTION BASED ON OUTPUT

with the average age of the most recently installed unit being 12 years. The largest number of newly installed units commenced operation 5-10 years ago (see Figure 9).

Between 1971 and 1972, within the State of Maryland there was a significant shift in power plant fueling from coal/oil operation to an all-oil or all-coal operation (see Figures 10 and 11). Note that in 1971, there were no power plants with all-coal operations and only one power plant with an all-oil operation. The rather anomalous shift in the energy source seems to indicate on the one hand the preference by some utilities for oil due to the minimization of the fly ash problem, and on the other hand the preference for coal by other utilities due to rising costs and shortages of fuel oil.

The amount of coal used by the coal-fired power plants surveyed during 1972 was about 2,185 tons per year per MW, while the amount of oil used by oil-fueled plants was about 8,088 barrels per year per MW.

In addition to waste heat and chemical effluents, fossil-fueled power plants also produce waste ash. During our power plant survey, extensive information on ash production, removal and disposal was also developed. The amount of ash that is produced by a power plant is dependent on the quantity and type as well as the ash content of the fuel. A total of 1,118,700 tons of bottom and fly ash were produced in 1972, from coal, oil and coal/oil operations by the power plants included in our survey. For all coal operation, the total amount of ash collected is about 317 tons per MW per year and represents less than ten percent of the coal used. On the other hand, the total amount of ash collected from all-oil operation is only about one tenth of a ton per MW per year.

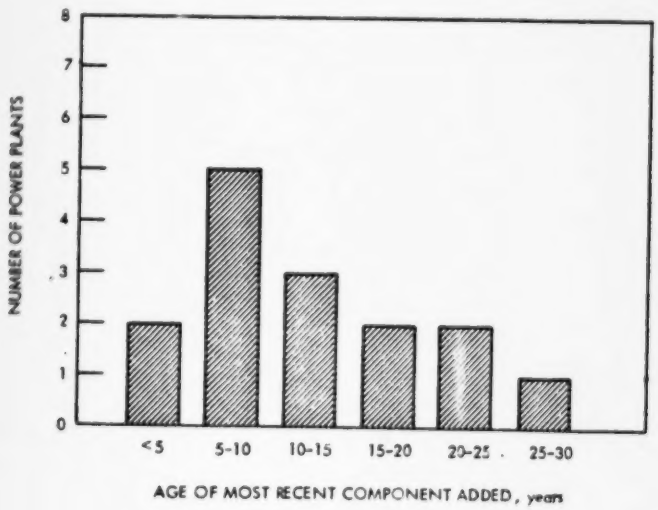


FIGURE 9 - POWER PLANT DISTRIBUTION ACCORDING TO AGE

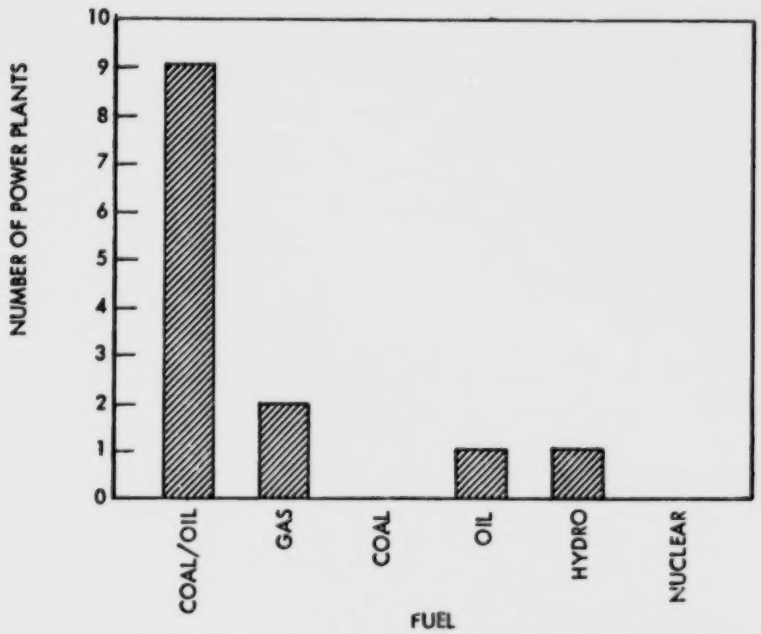


FIGURE 10 - MAJOR FUELING METHODS EMPLOYED BY POWER PLANTS WITHIN MARYLAND DURING 1971

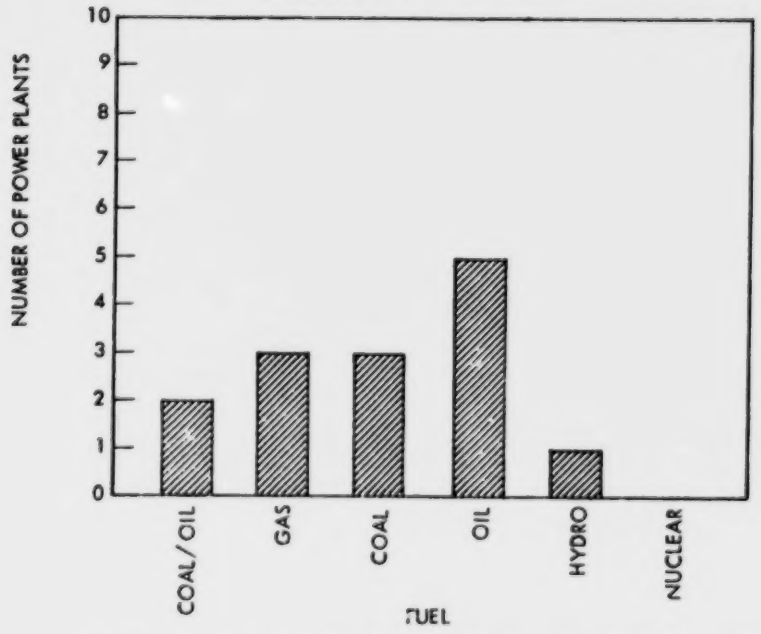


FIGURE 11 - MAJOR FUELING METHODS EMPLOYED BY POWER PLANTS WITHIN MARYLAND DURING 1972

The distribution of cooling methods employed by power plants surveyed is shown in Figure 12. As can be seen from the figure, the principal method employed presently is once-through cooling. The two cooling towers located in this area are operated by the Benning Road and Vienna Power Plants, and the cooling pond is operated by the Mt. Storm Power Plant. The cooling tower operated at the Vienna Power Plant (DELMARVA) withdraws its make-up water from the discharge canal of the once-through cooling system and discharges the blowdown to a settling pond. We were unable to obtain direct information on the cooling tower at the Benning Road Power Plant (PEPCO) or the cooling pond at the Mt. Storm Power Plant (VEPCO), although a description of the latter can be found in Reference 18.

IV.4 THERMAL LOAD

In 1972 the total generating capacity in the Maryland region was approximately 8644.7 MW. By 1980, when power plants presently under construction will be operating, the generating capacity will be approximately 11,595 MW, and by 1990, when currently proposed units are in operation, the power generation will be approximately 22,395 MW.[17] Thus, in a

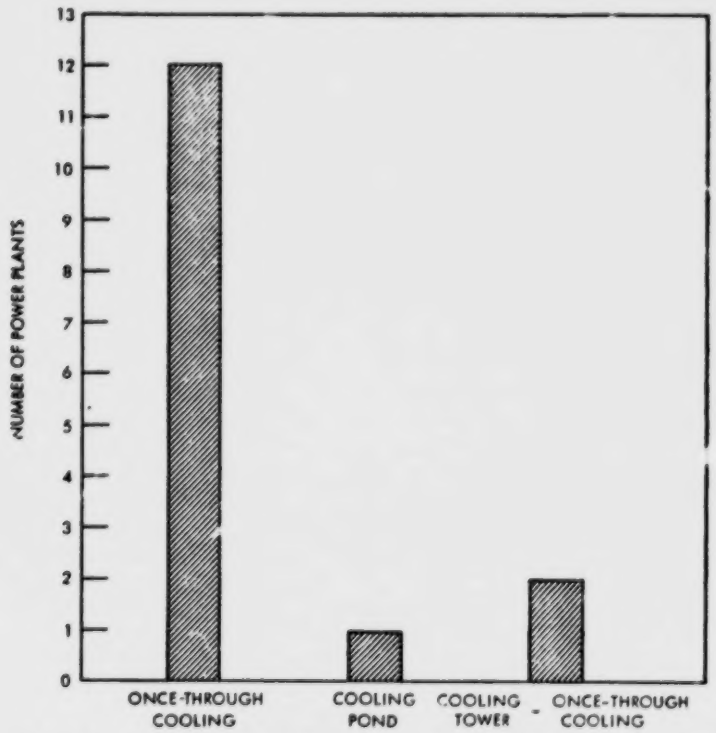


FIGURE 12 - COOLING METHOD DISTRIBUTION FOR THERMAL ELECTRIC POWER PLANTS WITHIN THE MARYLAND REGION.

period of less than 20 years, the potential for power generation within the region will nearly double. This growth rate of power generation in Maryland only slightly exceeds the projected growth rate for the Chesapeake Bay Region (see Figure 4). Hence, the projected growth trends for power generation and related water requirements within the Chesapeake Bay Region appears to be applicable to the Maryland region also.

The current rate of waste heat generation in the Maryland region is about 495 x 10^8 BTU's/hr at an average plant efficiency of 34.2%. However, the growth of power to 22,395 MW by 1990 will represent an increase in the waste heat generation rate of 650 to 750 x 10^8 BTU's/hr at an average plant efficiency of 35 to 40%. Thus, in a period of less than 20 years, the amount of waste heat to be dissipated will be nearly three times the amount presently being dissipated within the region.

IV.5 CHEMICAL LOAD

The power plants considered in this study employ a variety of chemicals in their cooling water systems in order to prevent fouling. While chlorine is most commonly used, other chemicals used are caustic soda, alum, sodium dichromate, sulfuric acid, Hagatreat and calcium hypochlorite. The type and quantity of the chemicals used in any cooling method are of considerable concern since most of these chemicals will ultimately find their way into a waterbody. The distribution of the different chemicals used in power plant cooling system can be found in Figure 13.

Chemical Treatment - Once-through Cooling

The techniques used with once-through cooling systems to control slime and fouling vary widely between different power plants. For example, the R. P. Smith Power Plant, with a capacity of 120 MW, described their operational procedure in slime and fouling control as follows:

> The plant minimizes chlorination. The condenser is allowed to become fouled. Then the fouled unit is shut down and the end plates are opened. The fouling material is allowed to dry, and the unit is placed in operation again. The initial surge of water through the condenser carries away the fouling material.

More often though, the power plants surveyed shock chlorinate to prevent fouling, and make minimal use of all chemical inhibitors when possible.

Chemical Treatment - Cooling Towers

The cooling tower at the Vienna Power Plant is a wet, mechanical, forced draft, crossflow, recirculating system, with plastic packing in the tower. The cooling tower is subject to chlorination by the residual

chlorine in the water withdrawn from the discharge canal, and does not undergo any further chemical treatment. It is claimed that the plant has not experienced any fouling problems using this system. No information is available on the techniques employed at the Benning Road Power Plant.

Chemical Treatment - Cooling Ponds

Mt. Storm uses caustic soda, and Hagatreat in the cooling-pond water; but, we have no data on the frequency of chemical use or on the effectiveness of the treatment, since they did not participate in our information survey.

IV.6 BOILER WATER SYSTEM

Boiler make-up water is generally drawn from the cooling water source and distilled; it is then passed through cation-anion ion exchangers and other commerically-available, chemical treatment systems to "polish" the water. The distribution of the chemicals used in the Maryland region is presented in Figure 14. While caustic soda and hydrazine are used by almost all of the plants surveyed, a wide variety of other additives are also used.

The blowdown from the boilers, even with the chemicals used in make-up, is relatively purer than the source water. All the power plants surveyed, with the exception of one, actively attempted water recovery from the boiler blowdown. The usual water-recovery method employed a flash tank or a flash evaporator. The blowdown from the flash tank or flash evaporator was then discharged back into the rivers without treatment since this blowdown was still relatively purer than the source water.

The one power plant that did not attempt water recovery from the boiler blowdown instead neutralized the blowdown and then discharged the waste into a settling pond located in a marsh area. The power plant did not give any explanation for its apparent lack of interest in water recovery.

During the survey, the power plants were questioned about the criteria they used in determining the proper time to blowdown the boiler. The power plants responded with a variety of answers, most of which could not be considered to be definitive.

IV.7 AUXILIARY ASH HANDLING SYSTEMS

As mentioned earlier, between 1971 and 1972 there was a significant shift in fueling methods. The major shift from a coal/oil operation (1971) to an all-oil operation (1972) appears to be a result of the

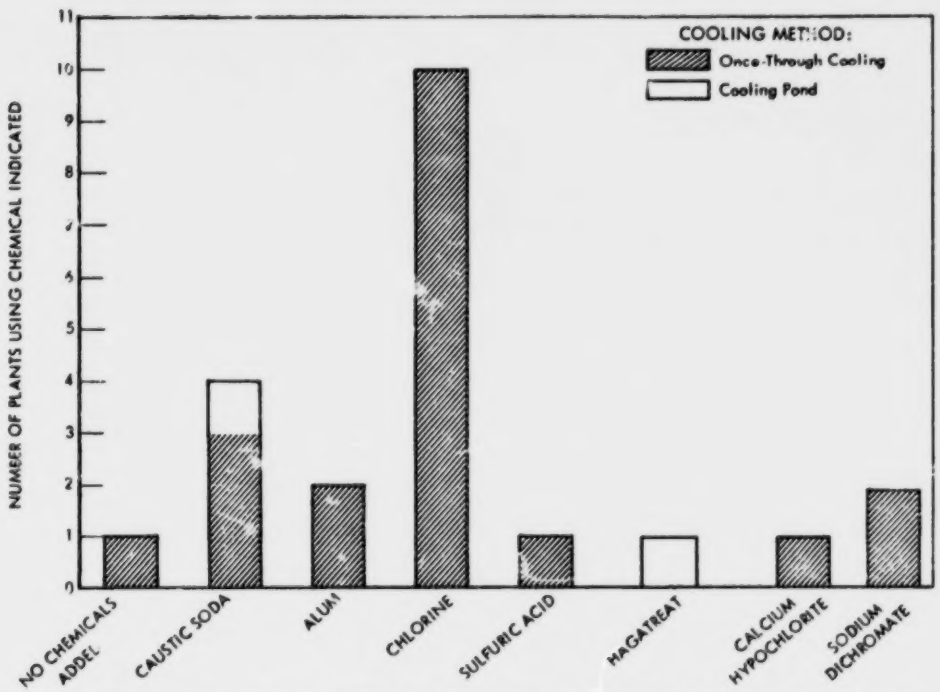


FIGURE 13 - DISTRIBUTION OF CHEMICALS ADDED TO COOLING WATER SYSTEMS

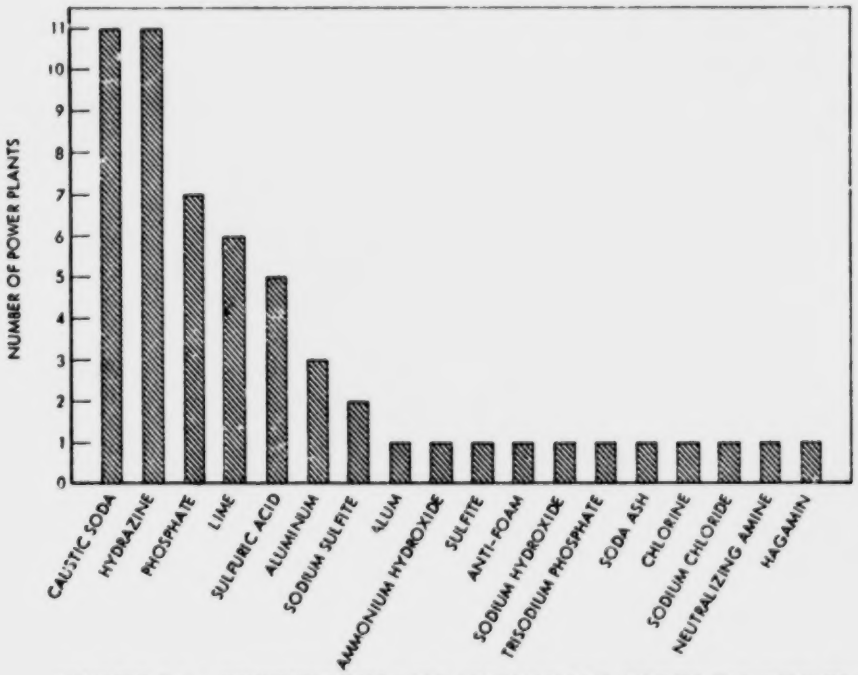


FIGURE 14 - DISTRIBUTION OF CHEMICALS ADDED TO BOILER WATER

interest in reducing the amount of ash and other particulates that result from a coal operation. During this period, there has been a net change of 107,854 tons of fly and bottom ash collected and disposed of.

All the power plants surveyed use flue cleaning equipment of either the electrostatic or mechanical cleaning type. The efficiency of this equipment averaged from 59% to 99.5% for the past year. However, these efficiency figures may be misleading in that power plants employing oil fuel with lower ash content may not require equipment with high efficiencies in order to meet clean air standards.

Most plants surveyed pay for the disposal of their ash-waste products. During the past year, only three plants sold waste ash, while two plants used the waste ash as land fill. Because of the relatively high cost of ash disposal, there appears to be a need for developing economical uses for the ash.

SECTION V

ENGINEERING ASSESSMENTS

V.1 GENERAL REMARKS

Section IV briefly investigated the data obtained from a comprehensive survey of selected power plants within Maryland. In the present section, the data are utilized to assess the heat-rejection and chemical-treatment effectiveness of various cooling methods, as well as to delineate the relevant general and economic factors. Factors influencing the quantity and quality of various waste effluents released into the aquatic environment are also examined. The objective of this section is to assess current power plant engineering practices to compare these practices with the "best available" technology and to forecast the improvements required in the state-of-the-art.

The assessments are carried out in this section primarily seeking semi-empirical correlations between the various principal factors involved, so as to: (1) establish a logical pattern of cause-effect relationships; (2) reduce the number of independent parameters involved in describing the environmental impact of power plant discharges. Thus correlations are sought between such variables as power-plant efficiency and age, amount of chemical added and cooling flow, cost of a cooling system and plant-generating capacity, and so on.

In the present section, the correlations themselves as well as the implications of the correlations for environmental-impact assessment are discussed. Where possible, the conclusions arrived at for present and future power plants in the Maryland region are generalized on a national basis.

V.2 THERMAL CONSIDERATIONS

The rate at which waste heat is generated by a power plant is a function of not only its capacity, but also of the efficiency of the various units that comprise the plant. The plant efficiencies within the Maryland region range from 28.8% at Vienna (DELMARVA) to 38.9% at Wagner (BG&E), with the average plant efficiency being 34.2%. The trend in the improvement of the efficiency of the power plants over the last several years is shown in Figure 15. As expected, the more recently constructed plants have higher efficiencies than the older plants, but plants with recently installed units also have high efficiencies, and this appears to be independent of the date the plant commenced operation. The anomalous high efficiencies occur for older power plants since many older units have been replaced with newer, more efficient units, thus improving the average efficiency of the plant. Taking this into account, it appears that,

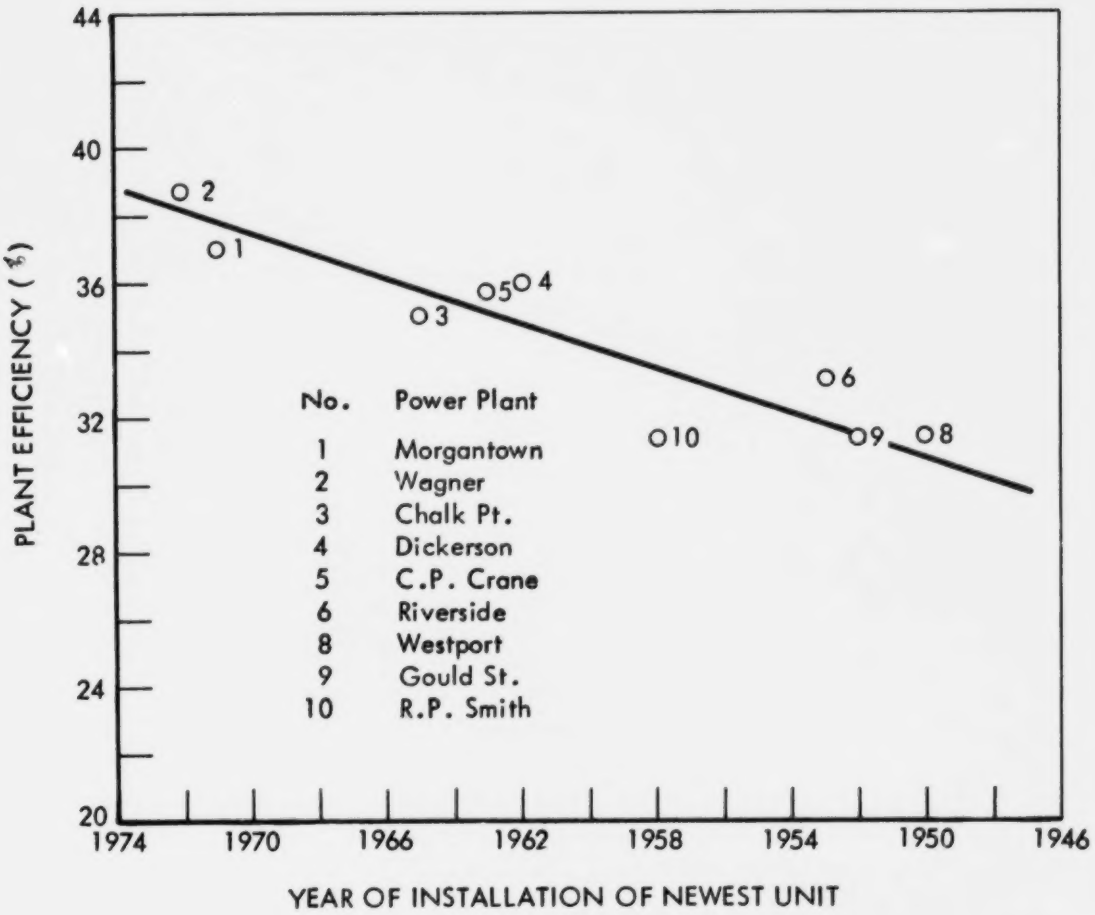


FIGURE 15 - PLANT AGE VS. EFFICIENCY

within the Maryland region, the efficiency of fossil fueled plants has improved at a rate of 0.3% per year. This regional figure compares well with national values for the improvement in plant efficiency (about 0.38% per year) for fossil fueled power plants (see Figure 2).

When water is used as the cooling medium, the waste heat has to be dissipated by using an appropriate temperature differential across the condensers. The temperature increases across the condenser, for the power plants included in our survey, are indicated in Figure 16. The average temperature rise is 15.1°F, which compares well with the corresponding national average value of 15°F that has been reported in a recent study[19]. In order to investigate any possible trends in this temperature differential with the age of the power plant, the former is plotted against the latter in Figure 17. The plant age shown in this figure is based on time since the installation of the newest unit. It can be seen from the figure that, in spite of the considerable scatter in the data, there is a very definite trend indicating that the newer power plants employ smaller temperature differentials than the older ones. This also correlates with power plant capacity, since the newest plant is also the largest (Morgantown - 1309 MW) and the older plants are of fairly small capacity (Gould St. - 156 MW, Westport - 194 MW and R. P. Smith - 129 MW).

To examine the relationship between the temperature differential across the condenser and the power plant capacity, these quantities are shown plotted against each other in Figure 18. The power plants are shown grouped according to age and at five-year intervals. Again, although the data exhibit considerable scatter, there seems to be a trend among both the older and newer plants toward smaller temperature differentials with increasing plant capacity.

While it is clear that design changes due to environmental concern are probably <u>not</u> the cause for the correlations observed, it is nevertheless worth noting that these correlations are significant when predicting the environmental impact, if the <u>temperature</u> of the discharges is of primary concern. In actual engineering design practice, the temperature rise across the condensers is a function of the type of cooling device used as well as the turbine back pressure (see Figure 19). In particular, as the temperature of the cooling flow increases, the turbine back pressure also increases. For best turbine efficiency an optimum value of the back pressure must be maintained; therefore, these factors, rather than environmental ones, influence the choice of the temperature rise across the condensers.

The temperature of the thermal discharge is the sum of the condenser intake temperature and the temperature increase across the condenser. The discharge temperatures for the power plants in the Maryland region can be found in Appendix B. The <u>average</u> discharge temperature for all

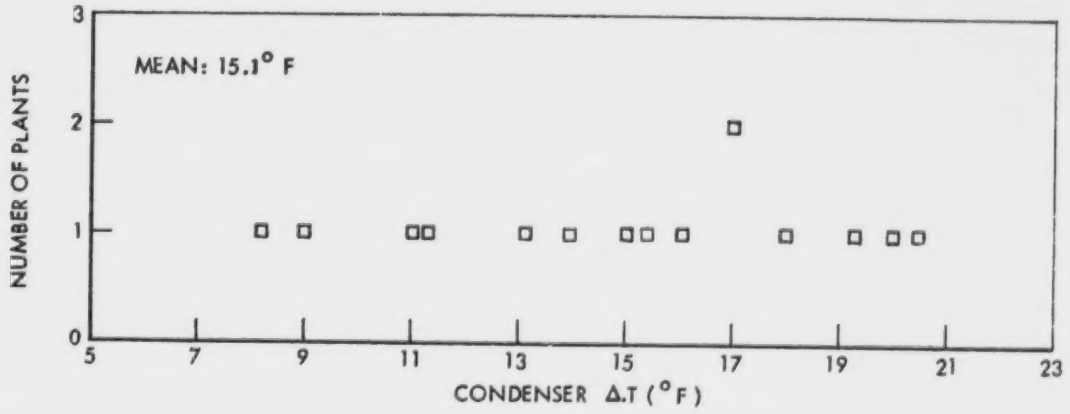


FIGURE 16 - PLANT CONDENSER Δ T (AVERAGE)

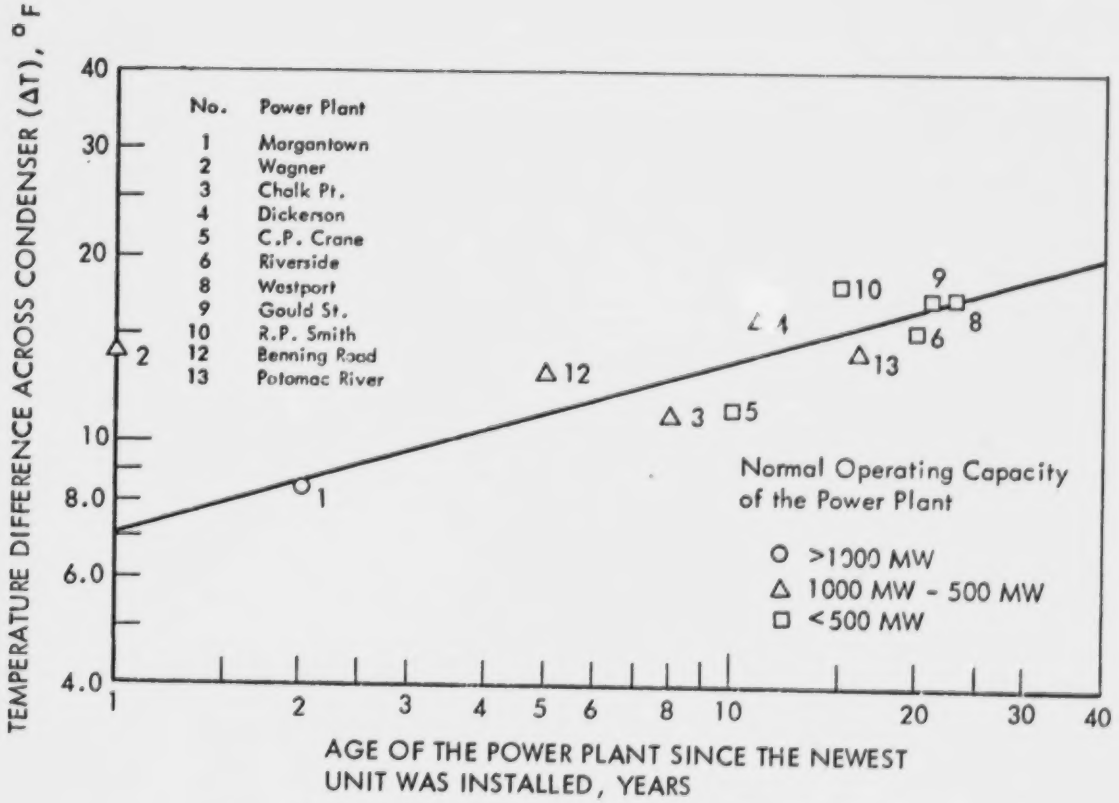


FIGURE 17 - CONDENSER ΔT VS. THE AGE OF THE POWER PLANT

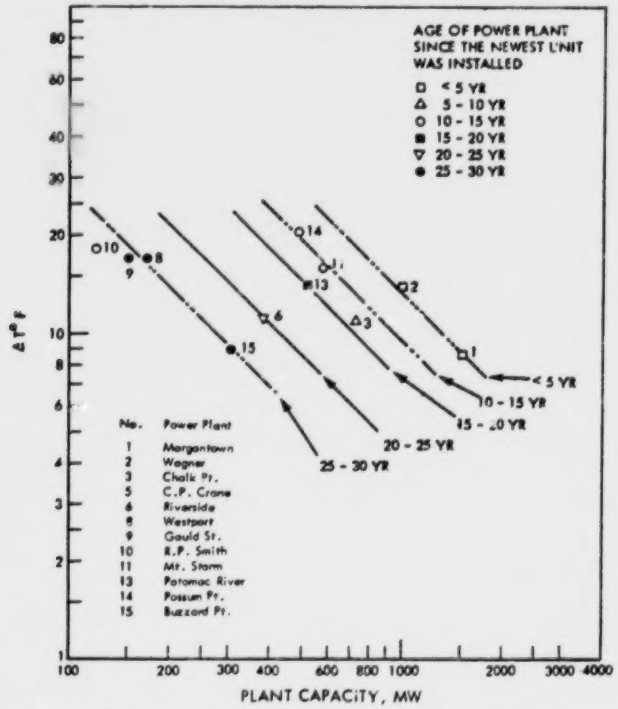
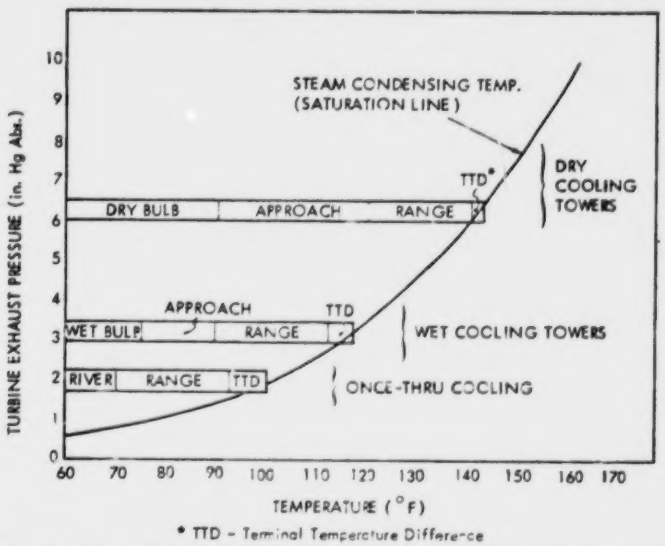


FIGURE 18 - SHIFT IN Δ T AS A FUNCTION OF PLANT CAPACITY AND AGE OF THE POWER PLANT SINCE THE NEWEST UNIT HAS BEEN INSTALLED



* TTD - Terminal Temperature Difference

FIGURE 19 - COOLING SYSTEM TEMPERATURE-EXHAUST PRESSURE RELATIONSHIPS (from reference 20)

the power plants in this region is below 90°F, and distribution of the maximum condenser discharge temperatures is shown in Figure 20. It should be noted that these temperatures do not necessarily represent the outfall temperature that is felt by a receiving body of water, since some power plants employ augmentation pumping in their discharge canal to reduce the outfall temperature. These temperatures do represent the maximum temperatures entrained aquatic life will encounter during passage through the condensers.

The average maximum discharge temperature for the plants studied employing once-through cooling is 99.6°F. This value should be compared with the nationwide average outfall temperature of 95°F reported in a recent study[19].

V.3 COOLING WATER REQUIREMENTS AND CONSUMPTION

When once-through cooling is employed, the amount of water required to dissipate the waste heat due to the generation of a unit of power is dependent on the overall efficiency of the power generation process. It has been pointed out earlier that, over the last few years, there has been a steady improvement in the efficiency for the power plants operating in the Maryland region. Thus it can be anticipated that there should have been a decrease in water use per unit power generation. On the other hand, the water use is also dependent on the temperature differential used across the cooling condensers and it was pointed out that the latter quantity has shown a tendency to decrease in recent years. The combined influence of the above factors, are presented in Figure 21 in terms of the variation of the water use per unit power generation with the age of the power plant. It can be seen from the figure that the water use per unit power generation seems to be nearly invariant with the age of the plant and has a value of about 1.5 CFS per MW of installed capacity. Thus it appears that, as far as water use is concerned, the effect of improved efficiency has been offset by the trend toward the use of smaller temperature differentials across the condensers. The implication of this result on the environmental impact of the power plant will be discussed in detail later.

Water losses, or water consumed in cooling is dependent on the cooling method employed. In cooling towers, water consumption results from evaporation, wind drift, and blowdown. In spray ponds consumption results from evaporation and wind drift, while in once-through cooling and cooling ponds the loss is mainly from evaporation. Drift losses from cooling towers and spray ponds are a function of wind speed and droplet size. Depending on the cooling method employed, drift losses can range from as low as 0.002% of the cooling flow ("salt water" cooling towers) to as high as 5% of the cooling flow (spray ponds)[11,21].

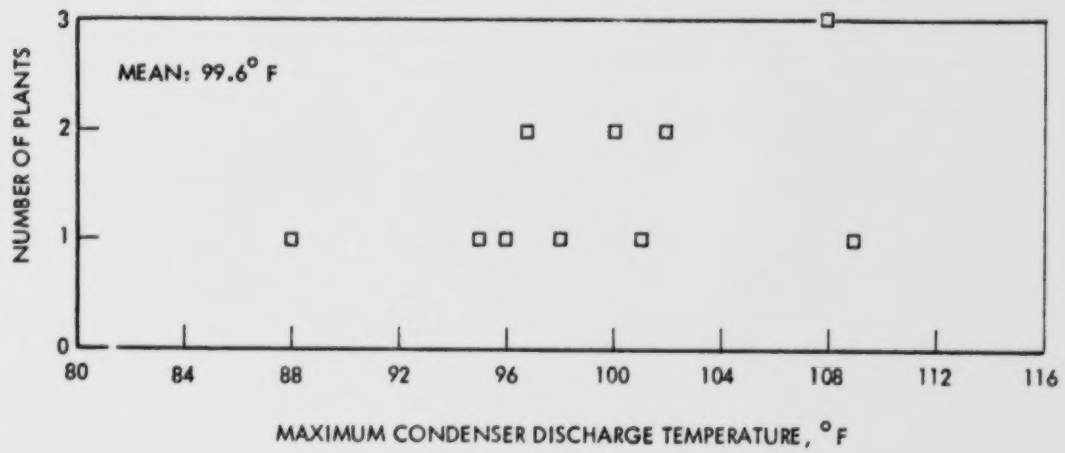


FIGURE 20 - MAXIMUM CONDENSER DISCHARGE TEMPERATURE

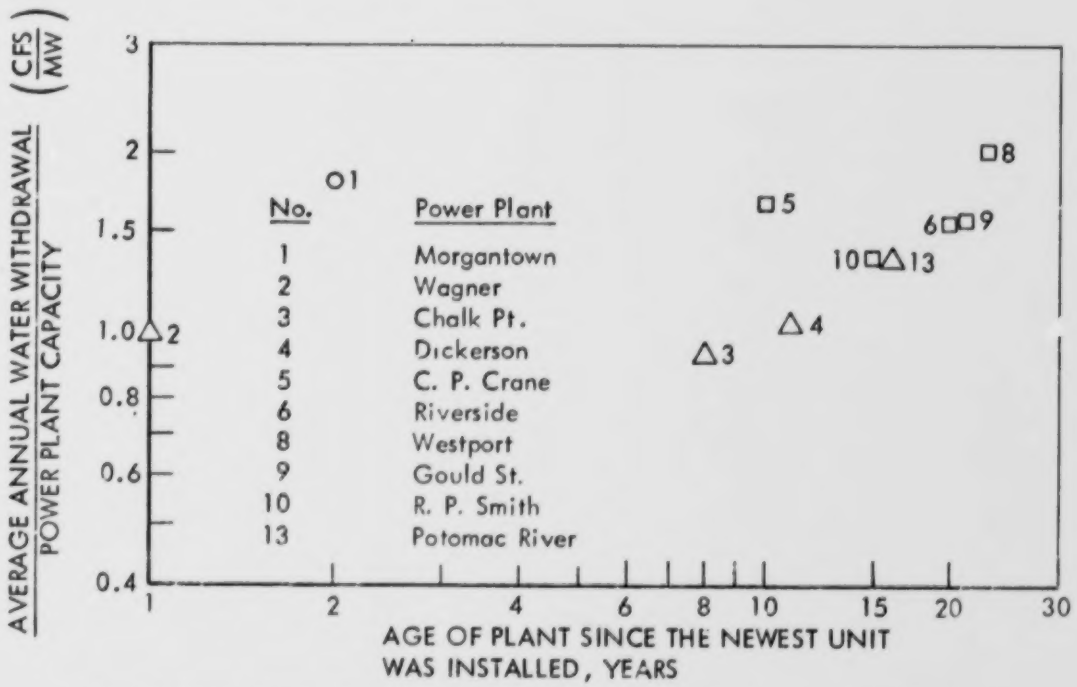


FIGURE 21 - RATIO OF THE AVERAGE ANNUAL WATER WITHDRAWAL TO THE POWER PLANT CAPACITY VERSUS THE AGE OF THE PLANT SINCE THE NEWEST UNIT WAS INSTALLED

Drift loss is an important consideration when siting a power plant in an estuarine environment. For example, the drift loss at the Vienna Power Plant is 0.0172 to 0.00529% at a flow rate of 23,500 GPM. This means that 1 to 4 gallons of brackish water per minute is lost to the environment The impact of salt deposition from brackish drift loss on the land surrounding a power plant site can be quite significant. A study is currently underway for evaluating this type of possible environmental impact from a mechanical draft wet-dry cooling tower at a porposed 1200 MW power plant site (Brandon Shores) in Maryland. The impact of this power plant is expected to be felt as far as 3.5 miles away, with an estimated deposition rate of 10 pounds of salt per acre per year[22].

Figures 22 through 27 show comparisons of evaporative losses and water consumption for various types of cooling methods, as functions of such factors as relatively humidity, wet-bulb temperature, cooling-water temperature, wind speed and cloud cover[20,23].

As can be seen in these figures, a natural lake or river has a smaller evaporative loss than a large cooling pond, while natural draft cooling towers, spray ponds, and mechanical draft cooling towers have water losses that are intermediate to those of cooling ponds and once-through cooling systems. A relative comparison of evaporative losses for various cooling devices are as follows:

Cooling Method	Evaporative Losses
Cooling Ponds	Greatest
Mechanical Draft Cooling Towers	
Spray Ponds	
Natural Draft Cooling Towers	
Once-through Cooling	Least

V.4 CHEMICAL TREATMENT EFFECTIVENESS

Most problems encountered in a cooling-water system originate with scaling, corrosion, or fouling of the system. The first step in making an analysis of chemical treatment effectiveness is to characterize scaling, corrosion or fouling. The more common scalants in a cooling system are[24]:

Calcium Carbonate	Magnesium Salts
Calcium Sulfate	Silica
Calcium Phosphate	Iron Oxide

Scale formation depends upon several factors such as the concentrations of alkalinity, calcium, magnesium, sulfates, phosphates, dissolved solids and silicas in the cooling water; also, the pH and temperature of the cooling flow (Reference 25).

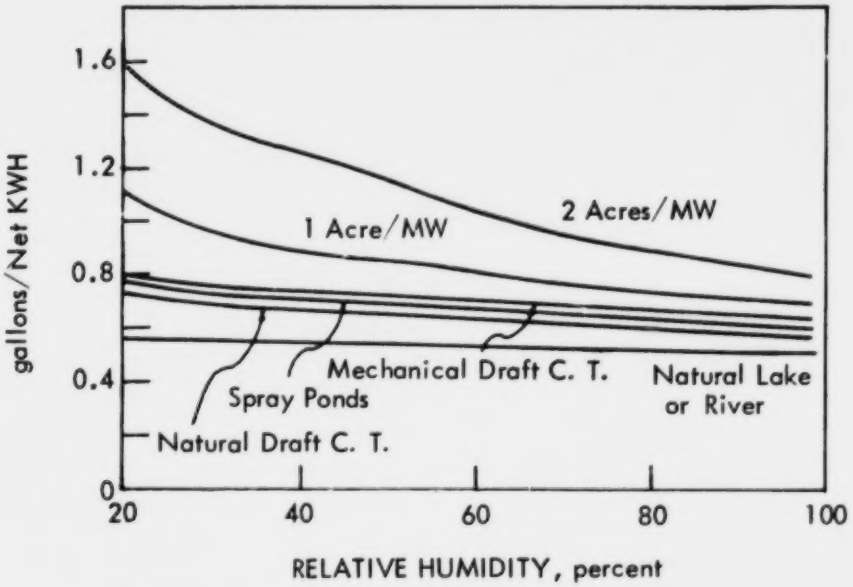


FIGURE 22 - A COMPARISON OF EVAPORATIVE LOSSES FOR VARIOUS TYPES OF COOLING SYSTEMS FOR VARYING RELATIVE HUMIDITIES (From References 20 and 23)

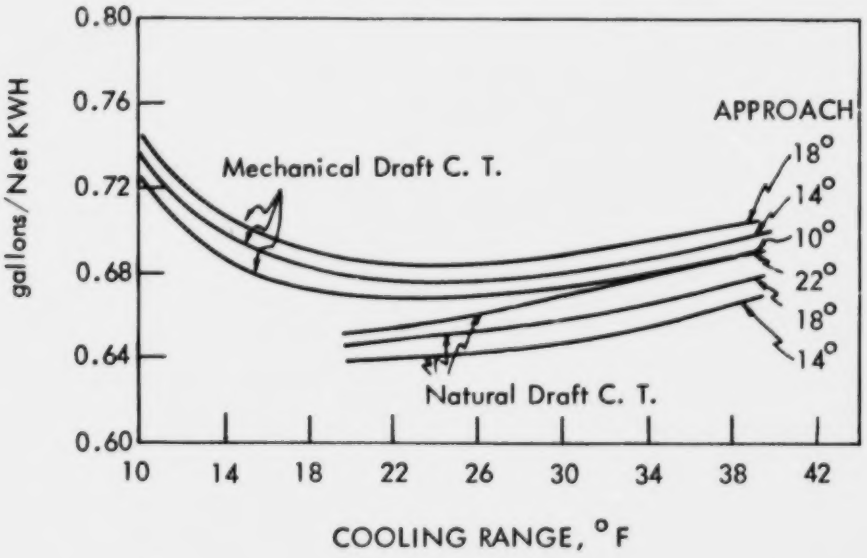


FIGURE 23 - A COMPARISON OF EVAPORATIVE LOSSES FOR VARIOUS TYPES OF COOLING SYSTEMS FOR VARYING COOLING RANGES (From References 20 and 23)

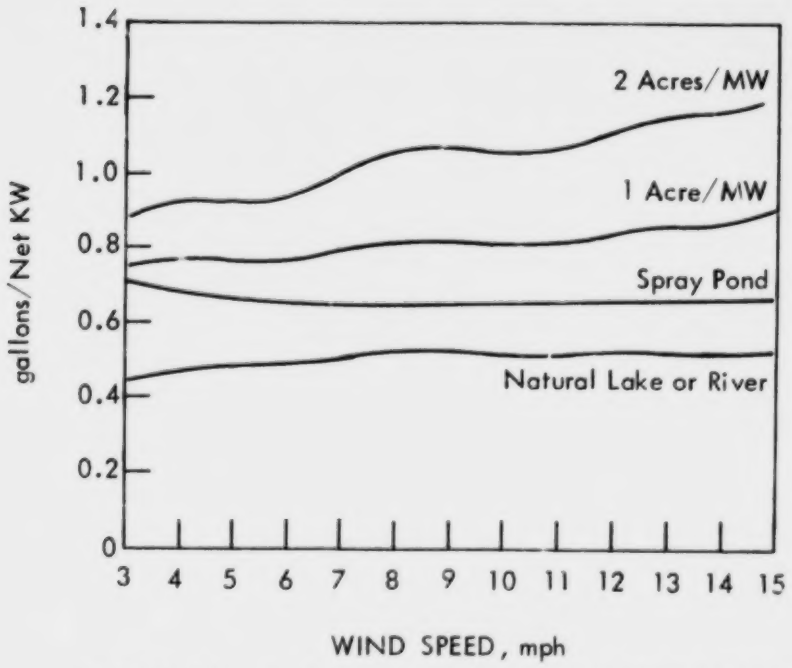


FIGURE 24 - A COMPARISON OF EVAPORATIVE LOSSES FOR VARIOUS TYPES OF COOLING SYSTEMS FOR VARYING WIND SPEEDS (From References 20 and 23)

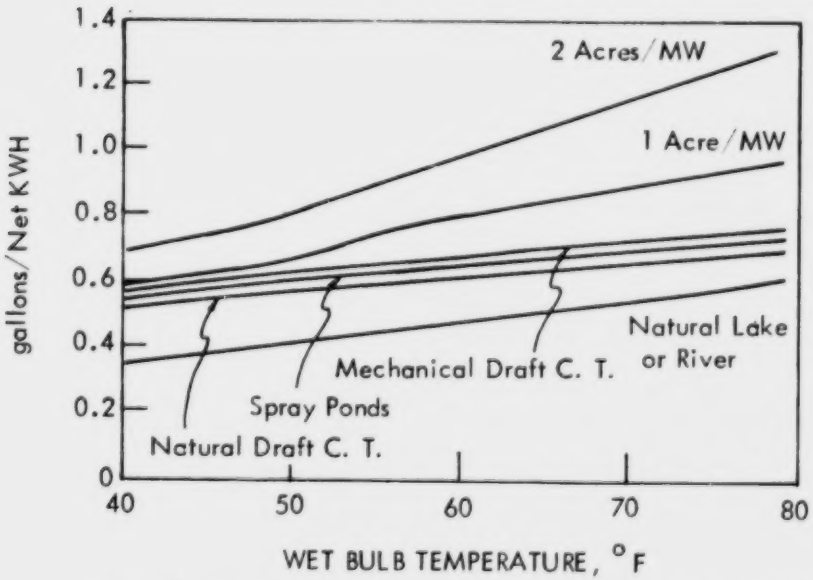


FIGURE 25 - A COMPARISON OF EVAPORATIVE LOSSES FOR VARIOUS TYPES OF COOLING SYSTEMS FOR VARYING WET BULB TEMPERATURES (From References 20 and 23)

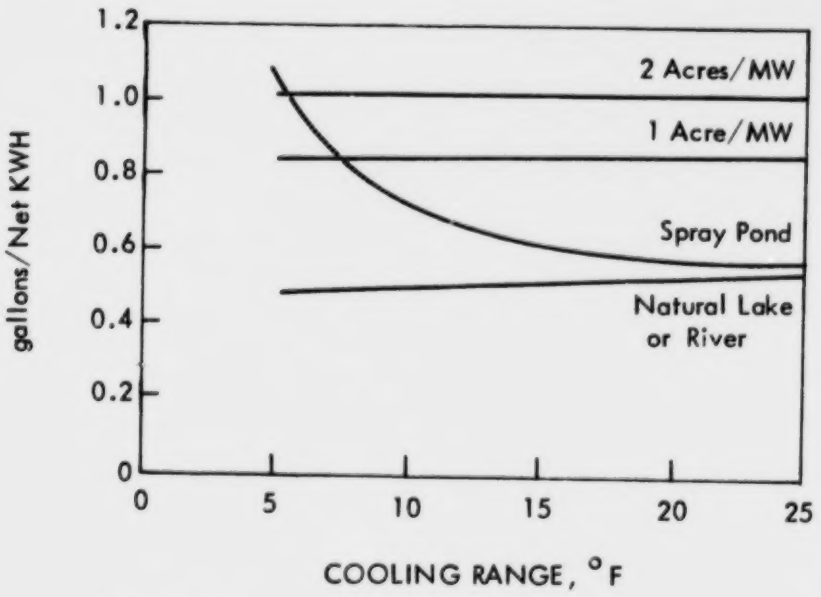


FIGURE 26 - A COMPARISON OF EVAPORATIVE LOSSES FOR VARIOUS TYPES OF COOLING SYSTEMS FOR VARYING COOLING RANGES (From References 20 and 23)

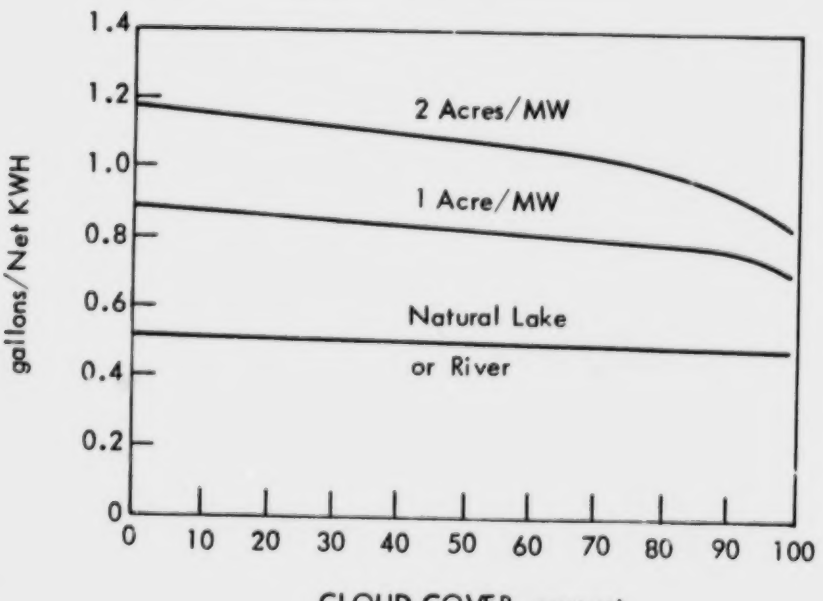


FIGURE 27 - A COMPARISON OF EVAPORATIVE LOSSES FOR VARIOUS TYPES OF COOLING SYSTEMS FOR VARYING CLOUD COVERS (From References 20 and 23)

The two most troublesome scalants found in a cooling water system are calcium carbonate and calcium sulfate. The solubility of calcium carbonate varies from 15 ppm at 32°F to 13 ppm at 212°F. Calcium carbonate scale is a thin eggshell-like scale and can be controlled by maintaining an adequate Langelier index. The Langelier index is an indication of the pH that must be maintained to keep the cooling-water system in equilibrium. When the pH of the water and the Langelier index (pH) are equal, then equilibrium is established. If the Langelier pH is lower than that of the circulating water, scale-forming tendencies are indicated, and when the Langelier pH is higher than that of the circulating water, corrosive tendencies exist. The most common way to control the pH is the addition of an acid, usually sulfuric acid (Reference 26). Most of the power plants surveyed in the present study did not compute the Langelier index, but closely monitored the pH of the cooling flow.

The addition of an acid to make-up water for the control of calcium carbonate scale formation often enhances conditions for calcium sulfate scale formation. The solubility of calcium sulfate, the second most common scalant, is a function of temperature and the presence of common ion-salts in the cooling water. Precipitation of calcium sulfate must be carefully controlled in evaporative cooling systems, since evaporative cooling is accompanied by an increase in the mineral concentration in the cooling flow. The limit of mineral concentration to avoid scalant formation must equal the ratio of calcium sulfate content at saturation to the calcium sulfate concentration of the acidized make-up water (References 27,28).

In a closed cycle cooling system, such as a cooling tower, water is evaporating continuously with the concentration of dissolved solids continuously increasing in the circulating water. To maintain the concentration of dissolved solids at some desired level within the circulating flow, water must be continuously blowndown to limit the dissolved solids buildup. The conservation-of-mass equation for this process can be expressed as

$$C_{MU}MU = C_B B$$

where C_{MU} = Concentration of dissolved solids in the make-up water

C_B = Concentration of dissolved solids in blowdown

MU = Amount of make-up

B = Amount of blowdown + drift loss

Since the concentration of dissolved solids in the blowdown is the same as the concentration of dissolved solids in the circulating water at the

time of blowdown, it is possible to express the number of concentrations (N) as

$$N = \frac{C_B}{C_{MU}}$$

The number of concentrations can be established by using calcium sulfate solubility as the limiting factor.

Figure 28 presents a method for estimating the maximum recirculation of cooling water prior to calcium sulfate saturation. Plotted in the figure are solubility curves for calcium sulfate in the presence of the common ion-salt of magnesium (Reference 27). The factors required for determining the maximum recirculation of the cooling water are: condenser discharge temperature, concentration of calcium sulfate in the make-up water, and concentration of magnesium salts in the circulating flow as calcium sulfate approaches saturation.

To use Figure 28, first locate the value of the condenser discharge temperature at the bottom of the figure. Determine the point where this temperature value intersects the magnesium salt concentration curve. The value indicated on the scale horizontally to the left of this point represents the maximum solubility of calcium sulfate in the circulating water. From this same point, locate horizontally to the right the point of intersection with the line representing the concentration of calcium sulfate in the make-up water. At this point there also is a diagonal line intersecting, and this line represents the maximum number of concentrations before calcium sulfate saturation. An example is included on Figure 28.

While Figure 28 does present a good estimate for the maximum allowable concentration of calcium sulfate in a cooling system, it has only limited use if the make-up water contains concentrations of an ion-salt that cannot be expressed as a magnesium salt. Other empirical and theoretical techniques for computing calcium sulfate solubility have been presented in recent years (see References 27,28,29,30), but all these methods require tedious calculations. There is a need for the development of a quick, simple and accurate technique for determining the maximum allowable recirculation of cooling water.

Calcium sulfate scale may be controlled by pretreatment of the make-up water. The calcium sulfate content of the make-up water may dictate the type of pretreatment that is best suited for reduction of the calcium sulfate. If make-up water has a hardness greater than 200 ppm of calcium as $CaCO_3$, then lime softening of the water may be suitable, while make-up water with less than 200 ppm of calcium as $CaCO_3$ may be best treated by

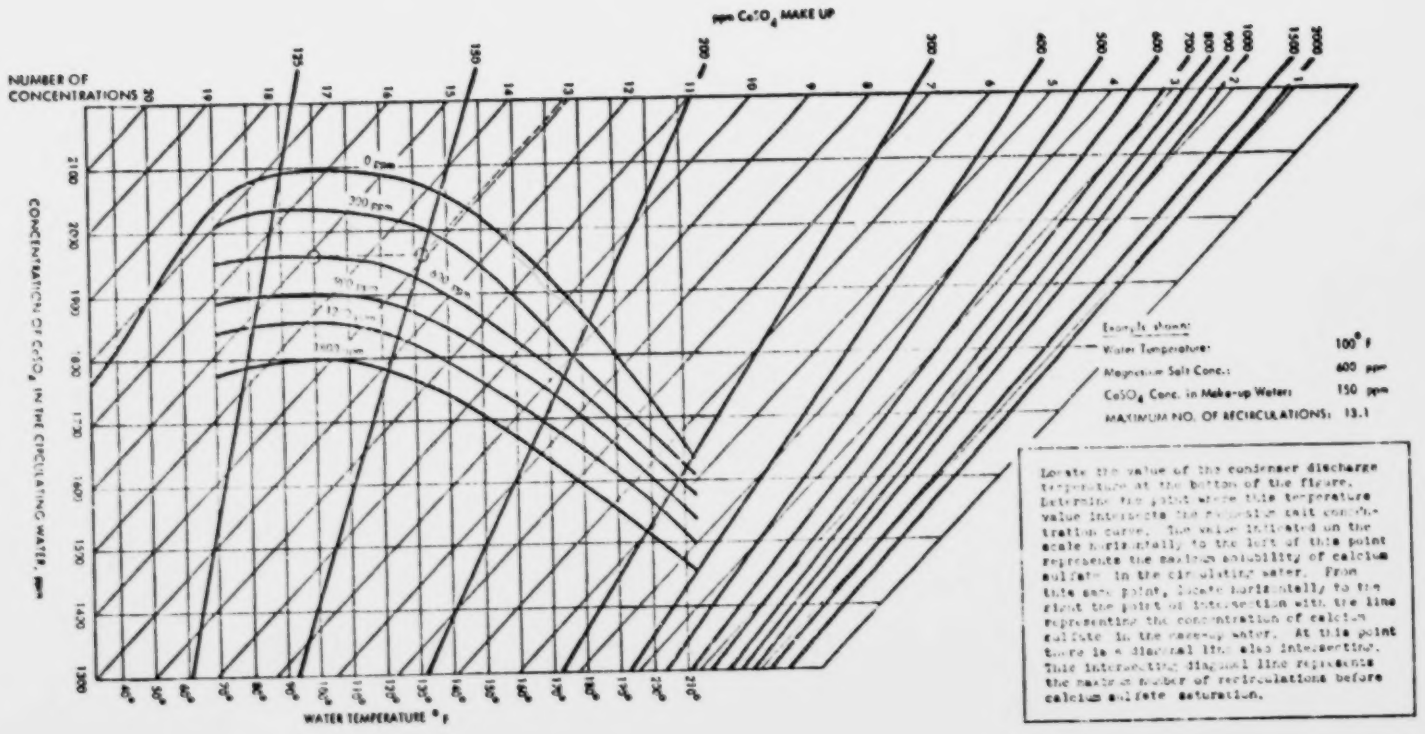

ppm $CaSO_4$ MAKE UP
NUMBER OF CONCENTRATIONS
CONCENTRATION OF $CaSO_4$ IN THE CIRCULATING WATER, ppm
WATER TEMPERATURE °F
Example shown:
Water Temperature: 100° F
Magnesium Salt Conc.: 600 ppm
$CaSO_4$ Conc. in Make-up Water: 150 ppm
MAXIMUM NO. OF RECIRCULATIONS: 13.1
Locate the value of the condenser discharge temperature at the bottom of the figure. Determine the point where this temperature value intersects the magnesium salt concentration curve. The value indicated on the scale horizontally to the left of this point represents the maximum solubility of calcium sulfate in the circulating water. From this same point, locate horizontally to the right the point of intersection with the line representing the concentration of calcium sulfate in the makeup water. At this point there is a diagonal line also intersecting. This intersecting diagonal line represents the maximum number of recirculations before calcium sulfate saturation.

FIGURE 28 - MAXIMUM RECIRCULATION OF COOLING WATER BASED IN THE SOLUBILITY OF $CaSO_4$ IN THE PRESENCE OF A MAGNESIUM ION-SALT

chemicals such as polyphosphates, organic-phosphates, chromates, organic-chromates, and other organic based chemicals which are also used in corrosion control (see References 25,31).

Corrosion can seriously hamper the heat transfer of a condenser and significantly shorten the life of a cooling-water system. The principal mechanisms that create corrosion in a cooling water system are[24].

Corrosive micro-organisms
Excessive oxygen content
Excessive carbon dioxide content
pH
Water velocity and temperature
Deposits

Corrosion inhibition is an area of cooling-water chemistry that requires further research. The effectiveness of various corrosion inhibitors needs to be investigated more thoroughly using various combinations of corrosion inhibitors for different operating conditions. In the past, chromates and polyphosphates were the most common corrosive inhibitors employed in power-plant cooling systems. But with increasing environmental awareness, highly toxic inhibitors such as chromates, polyphosphates and zincs have come under careful scrutiny and re-evaluation. Recent environmental studies have found that chromates have a toxic effect on algae at a level of .14 ppm, while zinc has a toxic effect on both algae and fish at nearly the same concentration, 0.64-0.09 ppm, (Reference 32). Chromates have had wide use due to high efficiency at low cost, while polyphosphates have been popular because of good corrosion inhibition properties and stabilizing characteristics which tend to minimize deposition of calcium carbonate and calcium phosphate scale and sludge (References 32,33).

The synergetic effect of similar corrosion inhibitors have frequently proven to be advantageous. Figure 29 shows the corrosion rate of steel coils under the influence of various corrosion inhibitors. For these tests the pH was held constant and the temperature varied. This figure was constructed from data compiled by Denman and Friedman[34].

Figure 29 indicates the corrosion inhibition of sodium polyphosphates, sodium chromates, and the synergetic effect of sodium polyphosphate and sodium chromate. From this figure it appears that, within certain temperature ranges and dosages, the synergetic effects of chemicals used in combination may improve the corrosion-inhibition properties of various chemicals.

Figure 30 shows the corrosion rate of a Drew single-tube heat exchanger when the corrosion inhibitor and its concentration were varied. These tests were made on standard water with a pH of 7. The temperature at which these tests were conducted is not clear from the report of Curtis and Silverstein[35]. Figure 30 represents a study of the synergetic effect

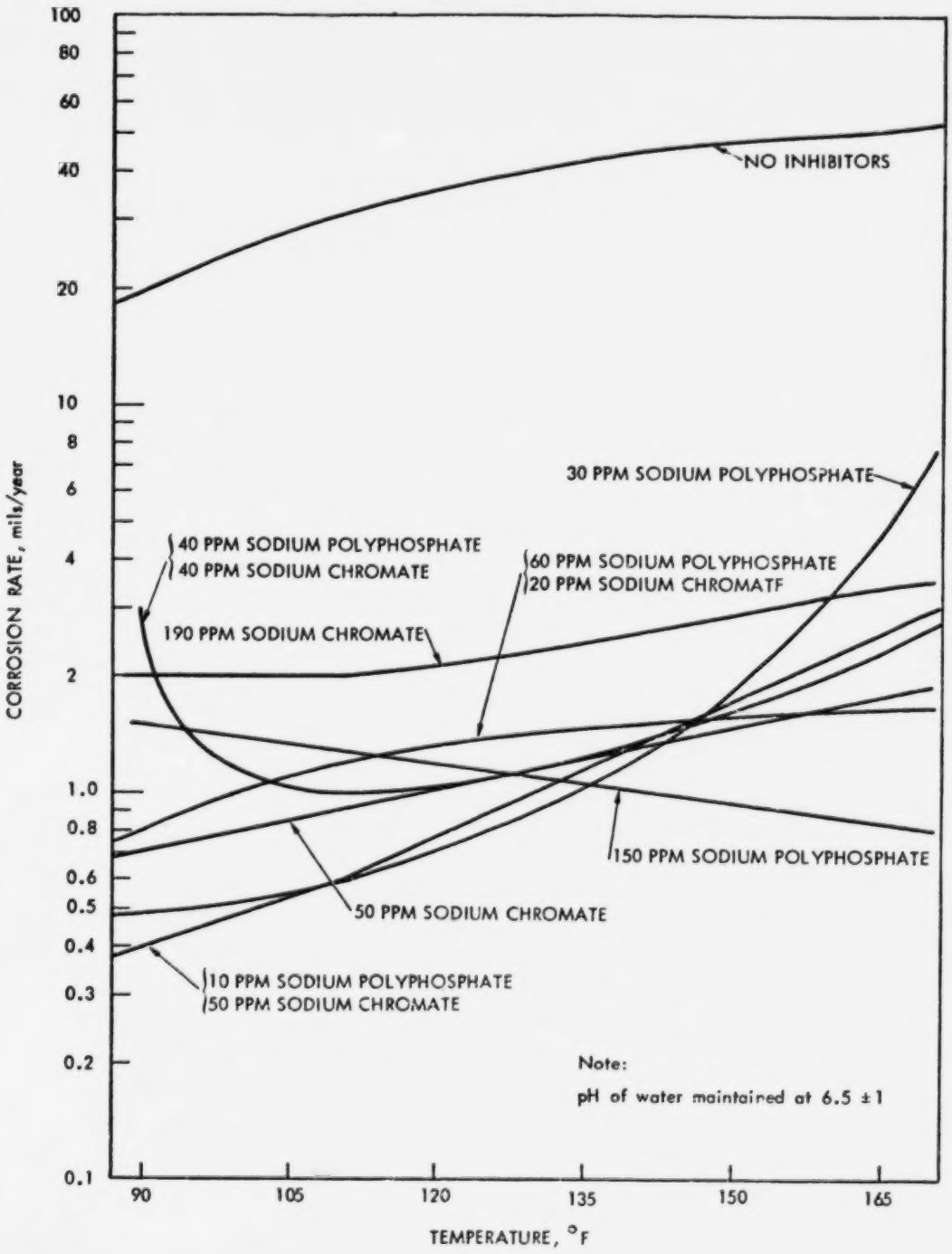


FIGURE 29- THE CORROSION RATE BASED ON THE USE OF COILS

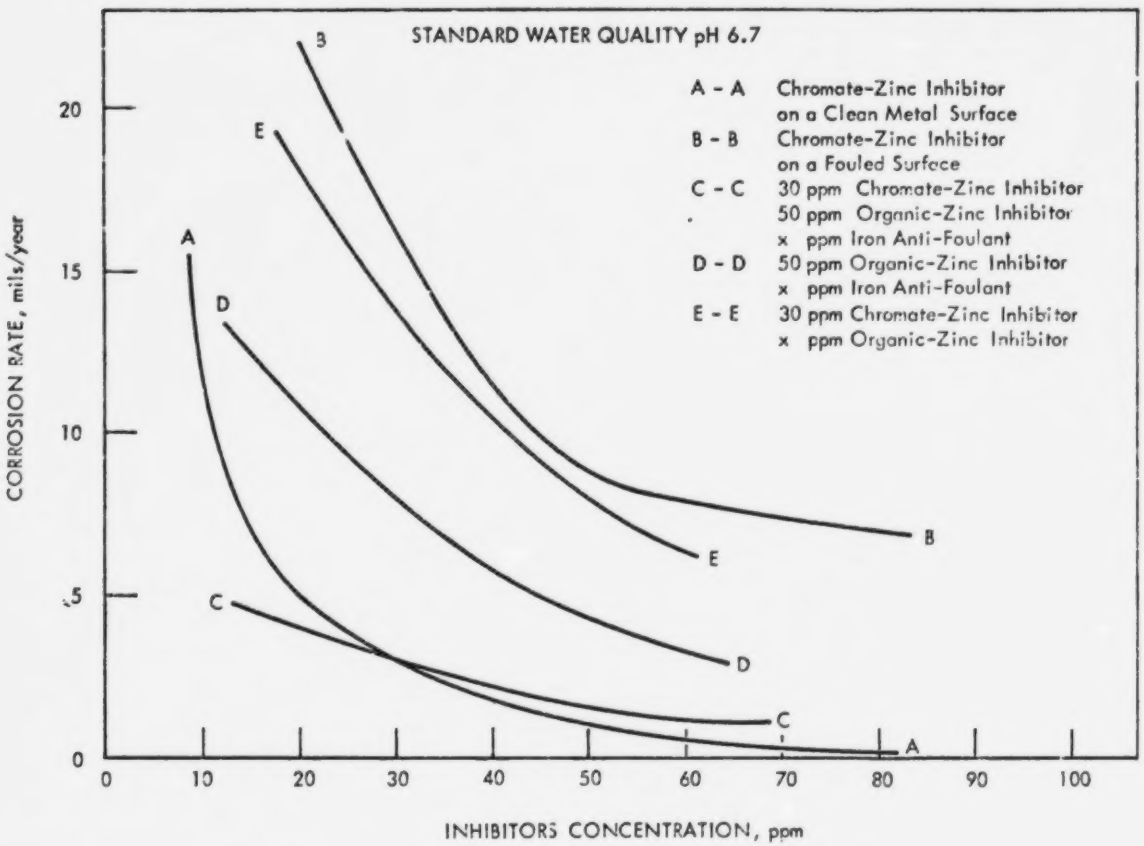


FIGURE 30- CORROSION RATE BASED ON THE USE OF A DREW SINGLE-TUBE HEAT EXCHANGER

when the concentration of the inhibitor is varied. This figure indicates that with increase in dosage of corrosion inhibitors, the corrosion rate drops. Figure 29 also indicates a similar result, although the efficiency of the corrosion inhibitor is based on a more complex relationship between cooling water-temperature, water quality, and the dosage ratio as well as the combination of corrosion inhibitors utilized. Significant amounts of work remain to be carried out before corrosion protection can be maximized and potential environmental problems can be minimized.

High corrosion rates and severe depositions on heat transfer surfaces have often resulted from the use of corrosion inhibitors at too low a dosage level during start-up. A proper dosage of corrosion inhibitors during start-up establishes a protective film. Once a proper protective film has been established, low corrosion rates and good heat transfer conditions can be maintained with carefully controlled pH and low corrosion inhibition dosages[36]. Typical dosages for corrosion inhibitors is shown below (see References 12,25,37,38).

Treatment Type	Dosage (ppm)	
	Initial	Maintenance
Polyphosphate-based (PO_4)	40-60	20-40
Organic-polyphosphate-based (PO_4)	40-60	10-20
Chromate-Phosphate (CrO_4)	40-60	15-30
Chromate-based (CrO_4)	40-60	15-20
Organic-Chromate (CrO_4)	40-60	5-15
Organic-based (total treatment)	200-300	50
Chromate-zinc		30
Sodium Chromate ($NaCrO_4$)		200-500
Sodium Nitrate		500
Ferrocyanides		30

The last area to be discussed under cooling-water-system chemistry is foulants. Foulants found in power plant cooling-water systems cover a wide range of substances (Reference 24):

Mud, silt, sand and clay
Corrosion inhibitors and products
Miscellaneous debris
Micro-organisms

Some of the factors influencing fouling are: make-up water contamination, suspended solids, iron, manganeses, and alumina in the cooling water, velocity, pH and temperature of the cooling flow (Reference 25).

The more common micro-organisms that are responsible for the fouling of cooling systems are:

Filamentous type organisms
Spore forming organisms
Non-spore forming organisms
Fungi (spore-forming molds)
Fungi (yeast-type), and
Algae.

The micro-organisms can be treated and controlled by anti-foulants, but products such as mud, silt, sand and clay present more serious problems. Theoretically, biological fouling problems can be controlled by using toxicants, although in actual practice, the treatment for microbiological control is much more complex than corrosion and scalant control. For corrosion and scalant control, the required amounts, costs and effectiveness of inhibitors can be predicted with some certainty, while this is not the case with microbiocides. With the use of an algicide to destroy active algae growths, it is often found that the bacterial activity in the cooling systems is greatly stimulated. Thus the algicide may have to be supplemented by a bacteriocide for bacteria control (Reference 39). The following is a list of commonly used biocides and bacteriocides (References 38,40,41):

Copper based salts
Amines of chlorobenzene
Bis-thiocyanates
Chlorophenols-chlorophenates
Chlorine

In the present study, Section III of the Power Plant Data Sheet (see Appendix A) was designed to enable the collection of sufficient information on the chemical treatment of cooling water systems employed by the power plants surveyed. The response from the power plants to this section of the questionnaire, as previously noted, was not entirely satisfactory, since only 17.8% of the applicable questions within the section were answered. The information collected during the survey was obtained primarily from power plants utilizing once-through cooling.

As mentioned previously, the majority of the power plants employing once-through cooling, shock chlorinate for fouling control. During the survey, the power plants did not report any serious fouling problems with their once-through cooling system. The frequency of chlorination by these power plants appears to be determined principally by traditional practices.

However, even from the limited data that was obtained, there appears to be an empirical relationship between cooling flow, water quality, and chlorination, see Figure 31. This figure indicates that as cooling flow increases, chlorination increases, though not in a simple linear fashion. Available data for 1971 and 1972 indicate that there is a relationship between water quality and amount of chlorine used. However, sufficient information was not available on the water quality of the Potomac and the Patapsco Rivers for the exact nature of the relationship between water quality and chlorination to be established. The empirical equation suggested by Figure 30, for estimating the amount of chlorine used by the once-through cooling system surveyed is:

$$\text{Amount of Chlorine Added, 1000 lbs/yr} = K \times (\text{cooling flow, CFS})^{.895}$$

where, K is a function of water quality.

After having evaluated the data on the other chemicals used in the cooling systems in this region, no definitive empirical relationships could be established. It should be noted here that due to the many factors that influence power plant design and operation, the empirical relations and conclusions being made here may not be valid universally.

Assessments on the cost of operation, maintenance, and chemical additions of cooling systems will be deferred until later.

V.5 GENERAL CONSIDERATIONS

During the survey, a number of significant aspects of power plant operations also became apparent. For example, there was a direct correlation between the thermal potential of the coal used and the power plant efficiency for the coal-fired plants surveyed. The observed correlation is shown in Figure 32, and it can be seen that as the thermal potential of the coal used increases, the power plant efficiency also increases. However, since the power plants surveyed reported their fuel quality on an "as burned" basis, a correlation between the thermal potential of the coal and plant might be expected. It is interesting to note that, even though the power plants surveyed also reported the quality of their fuel-oil on an "as burned" basis, a good correlation between the thermal potential of the oil and plant efficiency could not be found.

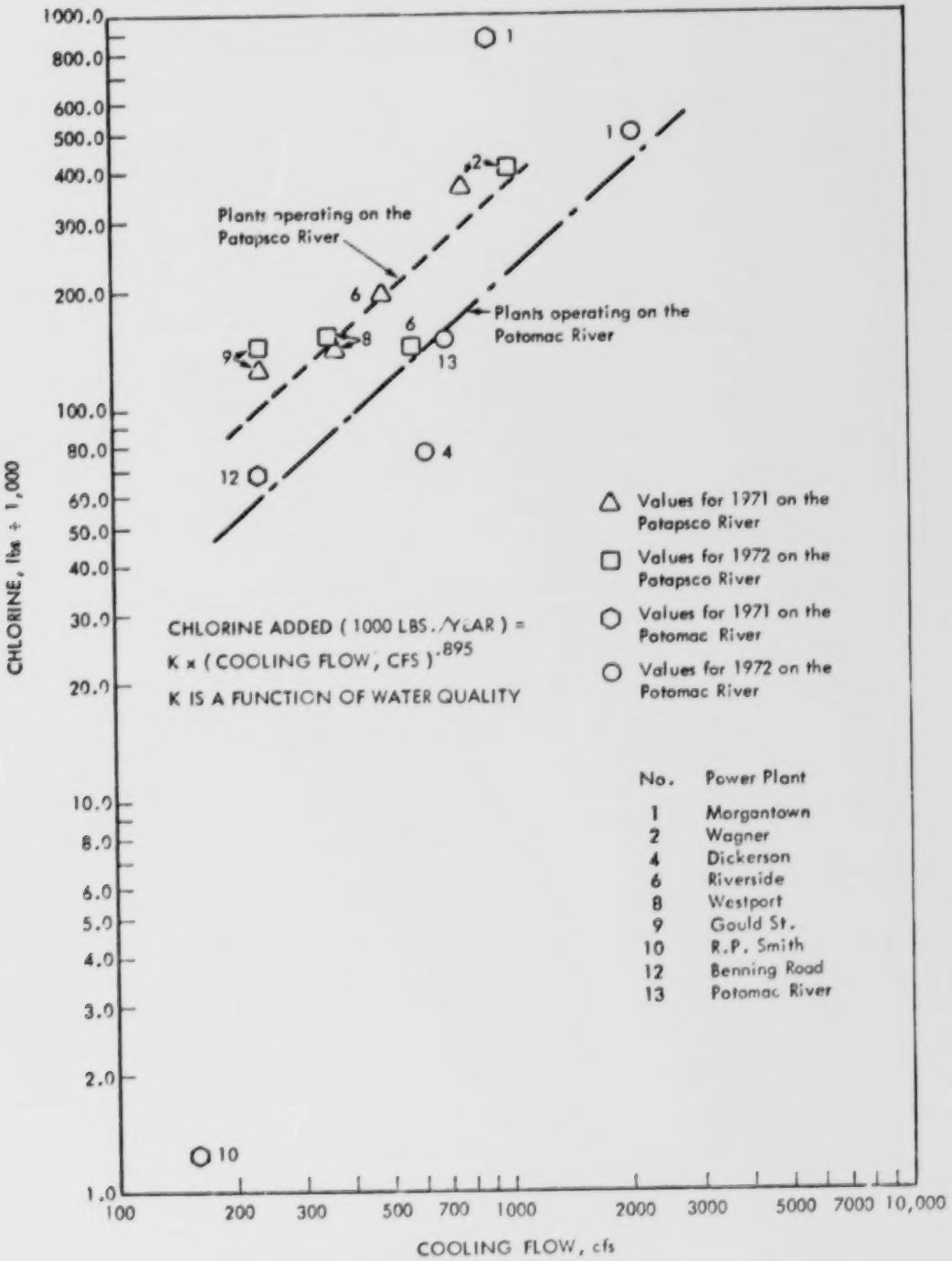


FIGURE 31 - CORRELATION BETWEEN CHLORINATION, COOLING FLOW, AND WATER QUALITY, WHEN EMPLOYING ONCE-THROUGH COOLING.

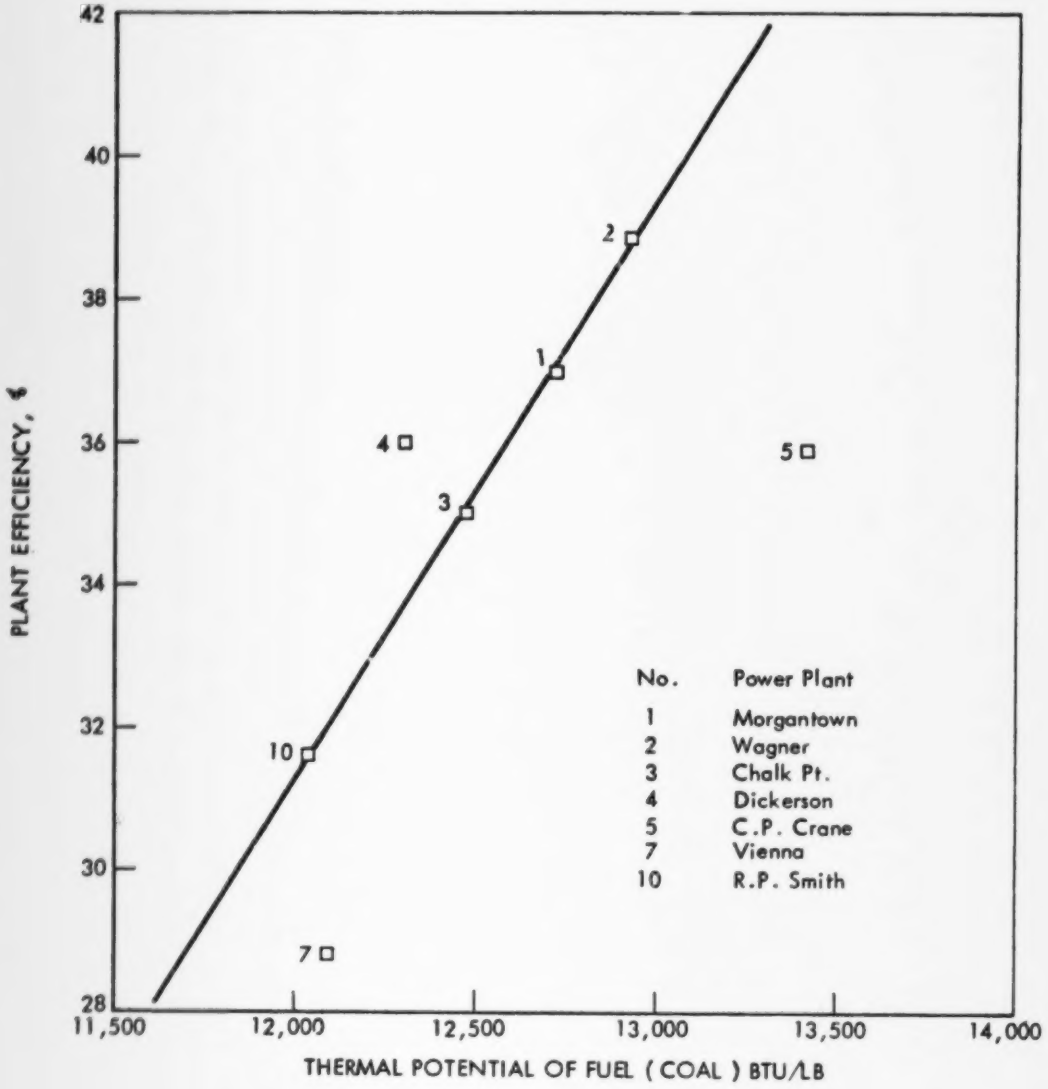


FIGURE 32 - CORRELATION BETWEEN FUEL HEAT POTENTIAL AND PLANT EFFICIENCY

None of the power plants surveyed employ stack scrubbing water but, instead, hose down their stacks and precipitator equipment with fresh water. The power plants operating with a brackish cooling-water supply usually obtain the hosing water from a municipal source, while the plants with a fresh water cooling supply usually obtain the hosing water directly from this supply. All the power plants have ash settling ponds where the hosing water was discharged. In these ponds, the waste ash is settled out prior to the waste water being discharged.

It is interesting to note that waste ash appears to be a very good filtration medium. During our visit to the R. P. Smith Power Plant, plant personnel told us of informal tests they had conducted on water entering and leaving their ash settling pond. The water entering the pond was high in suspended solids, while the water flowing into the Potomac River from the pond was of better quality than the water originally withdrawn from the river. (Unfortunately the data from these tests were not available.)

An interesting aspect of power-plant-siting practice also became apparent during the survey. Specifically, it was found that there exists a definite correlation between the capacity of a power plant and the size and distance of nearby towns as shown in Figure 33. Although no definitive conclusions can be drawn from this figure, it is interesting to note that as the capacity of the plant increases, the population of the nearest community becomes smaller, and the distance separating the community from the plant increases. This trend is evidently an indication that within the Maryland region the newer, large power plants tend to be sited farther away from population centers. The correlation is even more evident in Figure 34 where the products of the populations and distances are plotted versus the power plant capacities.

It is worth noting that this trend toward the siting of the large fossil-fueled power plants away from population centers can be expected to be more pronounced for nuclear-fueled plants.

V.6 ECONOMIC ASSESSMENTS

As a part of our survey, cost information on certain aspects of power plant operation has been compiled, and we have attempted to correlate some of this information in a meaningful way. Specific emphasis has been placed on those cost factors arising from the operation of control devices required for environmental purposes.

One of the considerations for any cooling method is the cost of the installed system. Four factors govern the installed cost of most cooling systems: (1) the total heat to be rejected by the device, (2) the approach of the device, (3) the range of the device, and (4) climological factors at the power plant site. The above four factors affect all

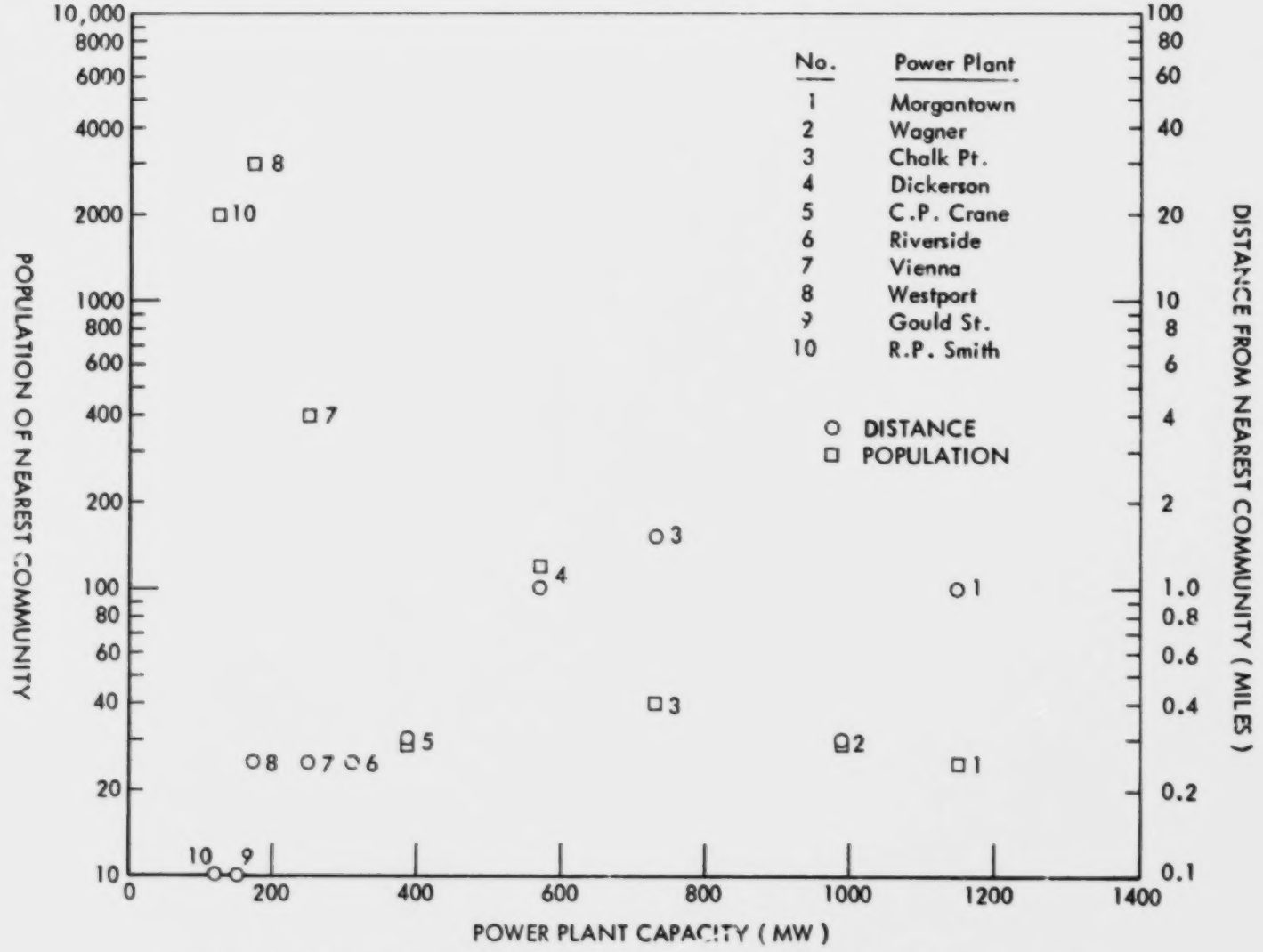


FIGURE 33 - RELATIONSHIP BETWEEN PLANT CAPACITY AND NEARBY COMMUNITIES.

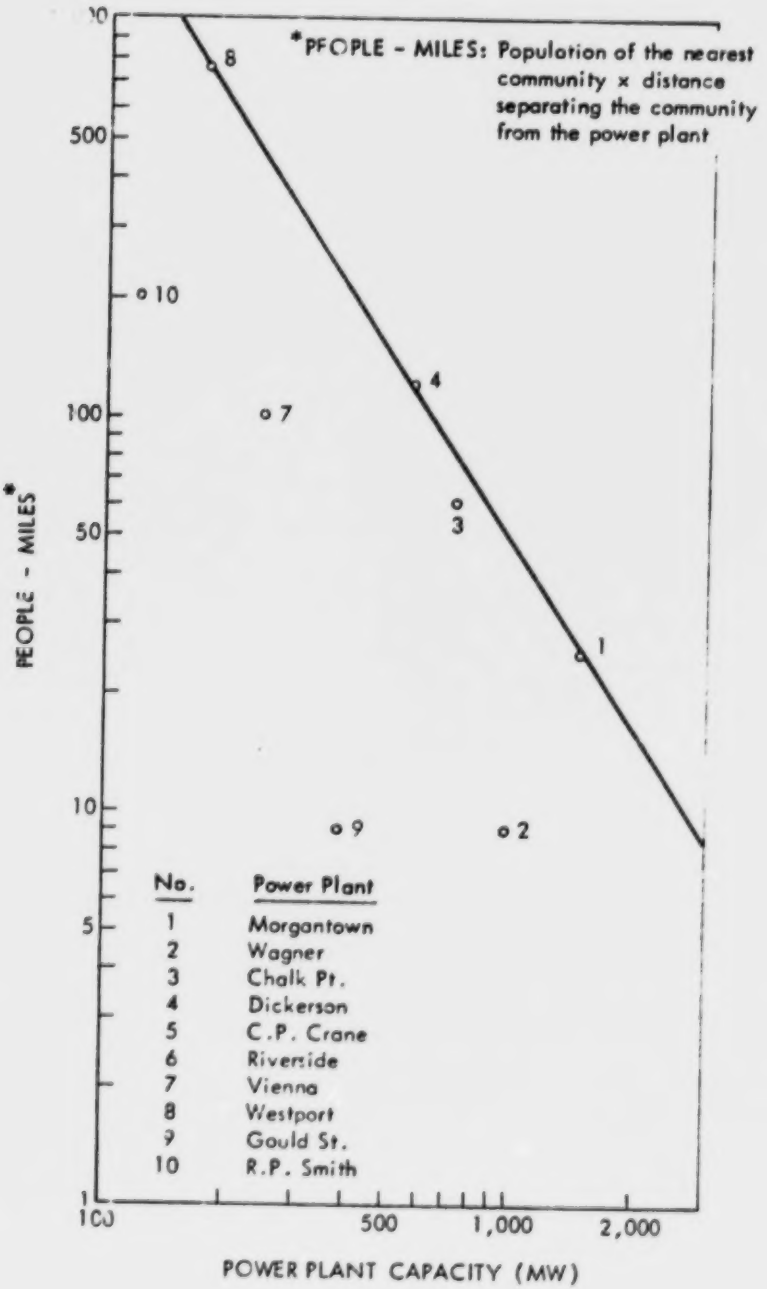


FIGURE 34 - RELATIONSHIP BETWEEN PLANT CAPACITY AND NEARBY COMMUNITIES

cooling methods with the exception of once-through cooling, where only factor (1) above need be taken into consideration.

As mentioned earlier, the most commonly used cooling method within the Maryland region is once-through cooling, with a total of fourteen power plants using this method. By utilizing the data acquired in our survey, we have attempted to assess the actual cost incurred in once-through cooling by the power plants within the Maryland region. In the following discussion, the installed cost of once-through cooling includes the costs for site preparation for inlet and discharge canals, piping, other materials and labor.

In the literature it is common practice to express the installed costs of cooling-systems in terms of dollars per kilowatt of power plant capacity. Accordingly, in Figure 35 the cost per kilowatt of the once-through cooling systems in the Maryland region are shown plotted against the power plant's capacity. Two factors are readily apparent from Figure 35. First, the average cost of $4-6 per KW is in reasonable agreement with available estimates (see Table 4). Secondly, there is a decreasing trend in the costs per unit power capacity with increasing capacity. The above factors would seem to indicate that the current practice of expressing installed costs of cooling systems in terms of cost/KW may not be a satisfactory one.

TABLE 4. INSTALLED COSTS OF VARIOUS COOLING METHODS

(Cost/KW)	
Once-through	$2.00 - $7.00
Cooling Ponds	$4.00 - $11.00
Evaporative Cooling Towers:	
Mechanical Draft	$5.00 - $13.00
Natural Draft	$6.00 - $16.00
Non-Evaporative Cooling Towers:	
Mechanical Draft	$18.00 - $35.00
Natural Draft	$20.00 - $41.00

Since the cost of installation can be expected to be more directly dependent on the amount of waste heat to be dissipated or the cooling flow required (these parameters being dependent on such factors as plant efficiency and condenser temperature differential in addition to power capacity), the data was examined to determine whether these parameters are more suitable for correlating the costs. The cost information was also adjusted to a standard year (1972) by utilizing the information contained in References 42 and 43 (see Table 5). The correlations are shown in Figures 36 and 37. From these figures it appears that the installed cost of once-through cooling does indeed correlate somewhat better with waste-heat and cooling-flow rates. The empirical relations indicated by Figures 36 and 37 are:

$$\text{Installed Cost, dollars} = 20{,}000 \times (\text{waste heat, BTU's/Hr}/1000)^{1.36}$$

$$\text{Installed Cost, dollars} = 97.4 \times (\text{cooling flow, CFS})^{1.59}$$

Installed cost information for cooling ponds and towers has been compiled from various sources[2,11,44,45,46,47] and can be found in Table 4. The cost estimates contained in this table should be viewed as only approximate, since the installed cost of a cooling system is influenced by the various factors cited previously. As can be seen, in Table 4, there is a considerable spread in the cost estimates that are available in the literature. Thus, while once-through cooling is the least expensive and natural-draft, non-evaporative "dry" cooling towers are the most expensive, there is a significant overlap in the costs of all the systems.

The cost of refitting power plants presently utilizing once-through cooling with various other alternate cooling methods is an important engineering consideration, especially since the enactment of PL92-500. There seems to be some disagreement in the literature regarding these costs. Thus based on a survey of power plants in the Great Lakes region, it has been estimated that the costs of refitting are significantly higher than the cost of new installations[48]. On the other hand, based on actual cases it has been reported that the costs of refitting with spray ponds is $3.87 per KW, while refitting with wet cooling towers the cost is $4.13 per KW[47] (both adjusted to 1972 dollars). It can be seen that these costs are somewhat lower than the cost of installation of entire new systems. The data available on the cost of the cooling tower that has recently been added at the Vienna Power Plant ($3.31/KW) supports a similar conclusion. The reason for the discrepancies in the reported costs may be that many of the factors influencing refitting can be site specific.

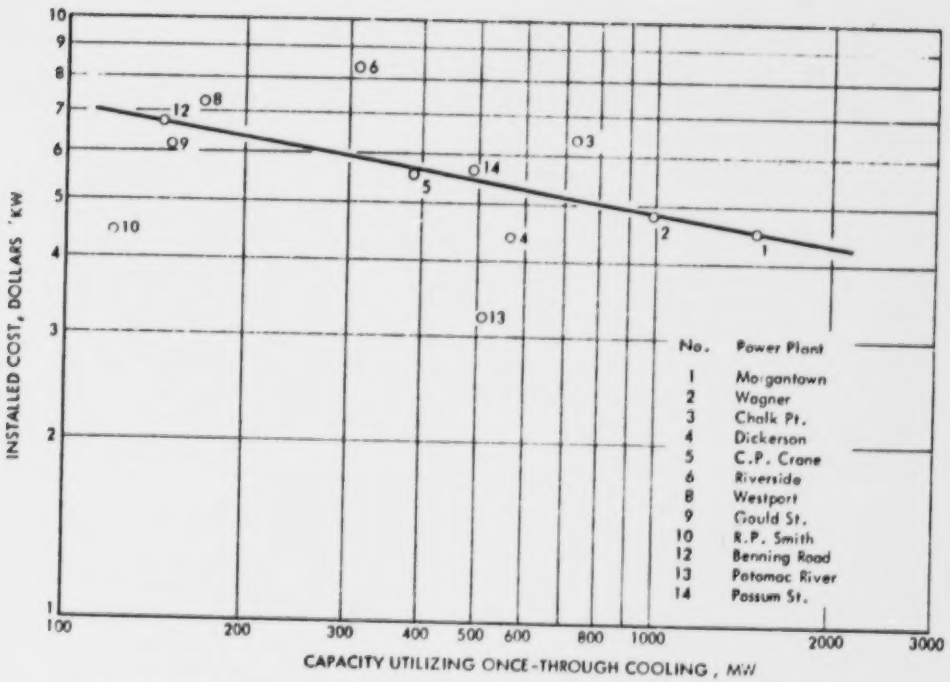


FIGURE 35 - ONCE-THROUGH COOLING INSTALLED COST/KW
(Condenser cost not included)

TABLE 5
DOLLAR VALUES *

Year	Amount
1903	$ .28
1906	.31
1923	.70
1926	.61
1927	.55
1933	.46
1942	.64
1948	1.14
1949	1.12
1956	.88
1959	.79
1961	.85
1964	.96
1965	.93
1970	.81
1978	1.00

* Used to purchase $1,000's worth of 1970 goods and services.

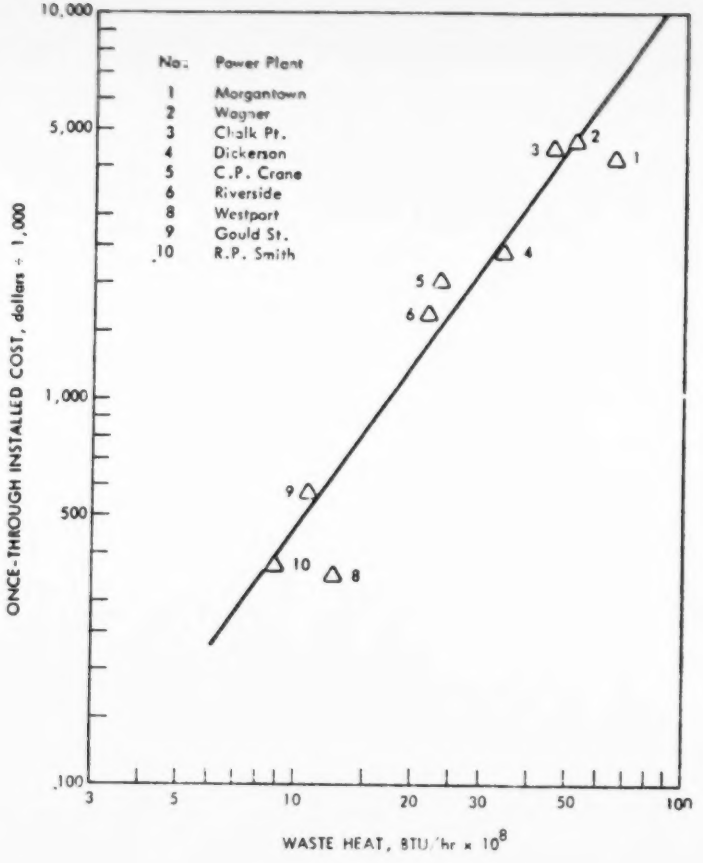


FIGURE 36 - INSTALLED COST OF ONCE-THROUGH COOLING VS. WASTE HEAT DISSIPATED, VALUES ADJUSTED TO 1972 DOLLARS

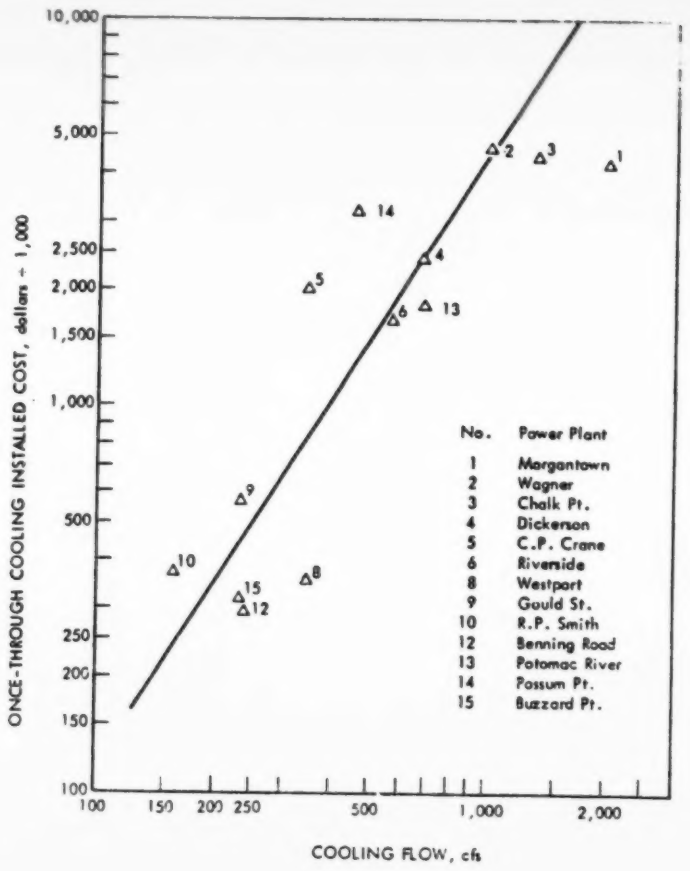


FIGURE 37 - INSTALLED COST OF ONCE-THROUGH COOLING VS. COOLING FLOW, VALUES ADJUSTED TO 1972 DOLLARS

Along with installed costs, another important consideration in cooling-system selection is the anticipated cost of operation and maintenance. During the power plant survey, extensive information was obtained on not only the cost of routine operation and maintenance, but also on the cost of chemicals added to the cooling water. Figure 38 shows the variations in the costs of maintenance and operation with power-plant capacity, while Figure 39 shows the variations with cooling flow. It is interesting to note that while the scatter of the data is considerable, the trends indicated in the figures are reasonable. The cost of chemical treatment is only a small fraction of the total operation and maintenance costs.

Assessments were also made on boiler-water costs. The total costs, including the cost of boiler blowdown and make-up, operation and maintenance as well as chemical addition, are shown in Figure 40 for the power plants surveyed. It can be seen from Figure 40 that the total cost, when expressed as cost per kilowatt per year, seems to be independent of power plant capacity and has a mean of about 10¢ per year per kilowatt of rated capacity. It should be noted that, as mentioned earlier, boiler blowdown is usually left chemically untreated since it is often of better quality than the original water source. Thus, the chemical cost is usually the cost of chemicals added to the make-up water. For a more detailed cost breakdown, Appendix B should be consulted.

To complete the economic review of auxiliary equipment operation and maintenance, information on the cost of collecting and disposing of fly and bottom ash was also compiled during the power plant survey. The cost of collection and disposal of ash is plotted versus the amount of ash collected in Figure 41. The data available for 1971 and 1972 are included in this figure. The cost of collection and disposal of fly ash is dependent on the ash content of the fuel as well as the efficiency of the precipitator used to remove the ash from the stack gases. These dependencies become apparent in Figure 42. It can be seen that the cost of collection and disposal varies between 2 and 9 dollars per ton. The unit cost decreases with increasing ash content in the fuel, but increases sharply with increasing precipitator efficiency, reflecting the fact that it is quite expensive to remove the last few tenths of a percent of the ash from the flue gases.

V.7 COMMENTS ON "BEST AVAILABLE" STATE-OF-THE-ART

One of the initial objectives of the present study was to assess the treatment methods actually being employed in terms of the "best available" methods within the current state of the art. However, a necessary prerequisite to such an assessment is a clear definition of what constitutes "treatment". Thus by treatment it can be meant that any water that is withdrawn from a waterbody has to be returned to its original state before it could be discharged back to the waterbody. On the other hand,

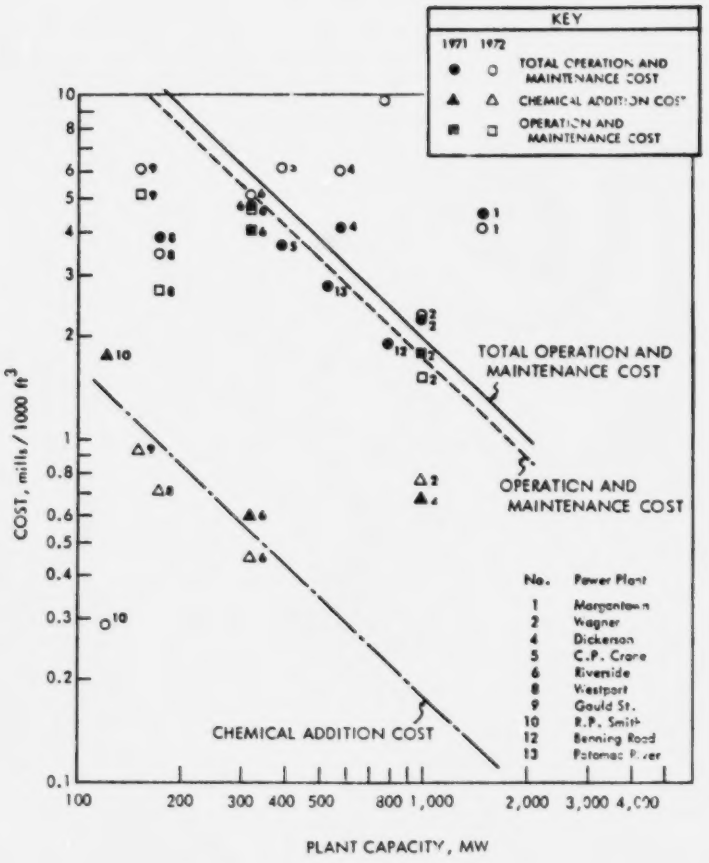


FIGURE 38 - ONCE-THROUGH COOLING SYSTEM OPERATION AND MAINTENANCE COST VS. THE PLANT CAPACITY

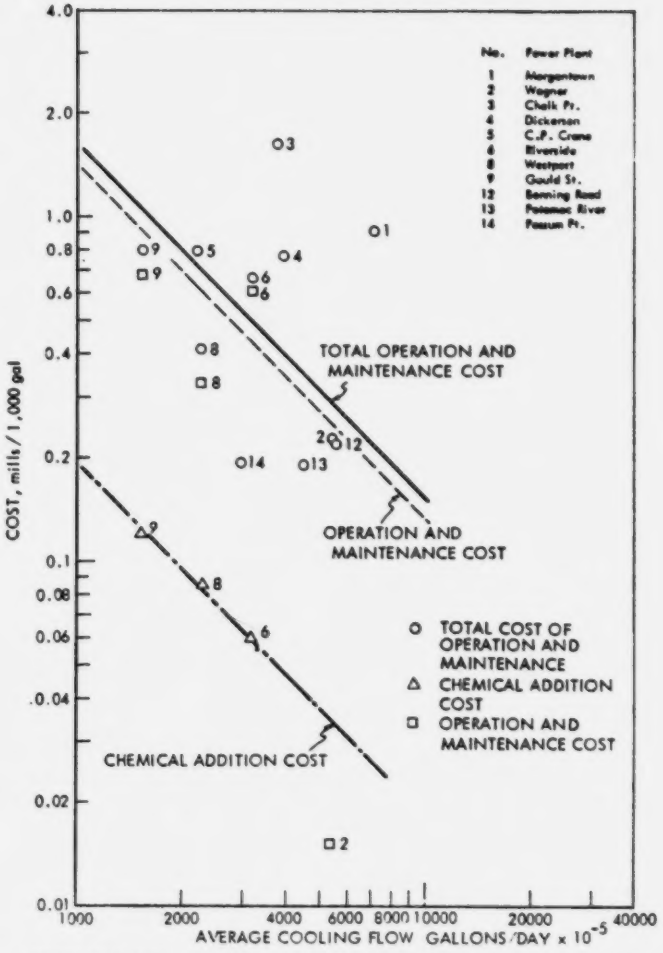


FIGURE 39 - TOTAL COST OF OPERATION AND MAINTENANCE AND CHEMICAL ADDITIONS OF A ONCE-THROUGH COOLING SYSTEM VERSUS COOLING FLOW PER DAY

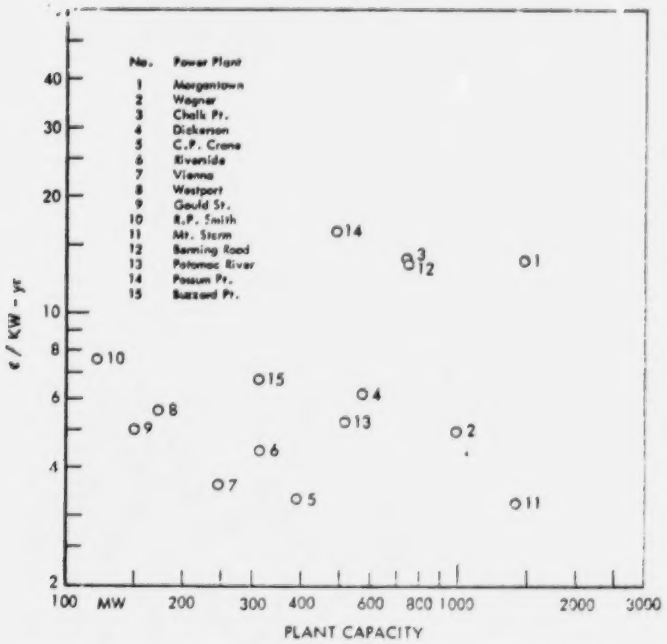


FIGURE 40 - BOILER WATER TOTAL OPERATING AND MAINTENANCE COST

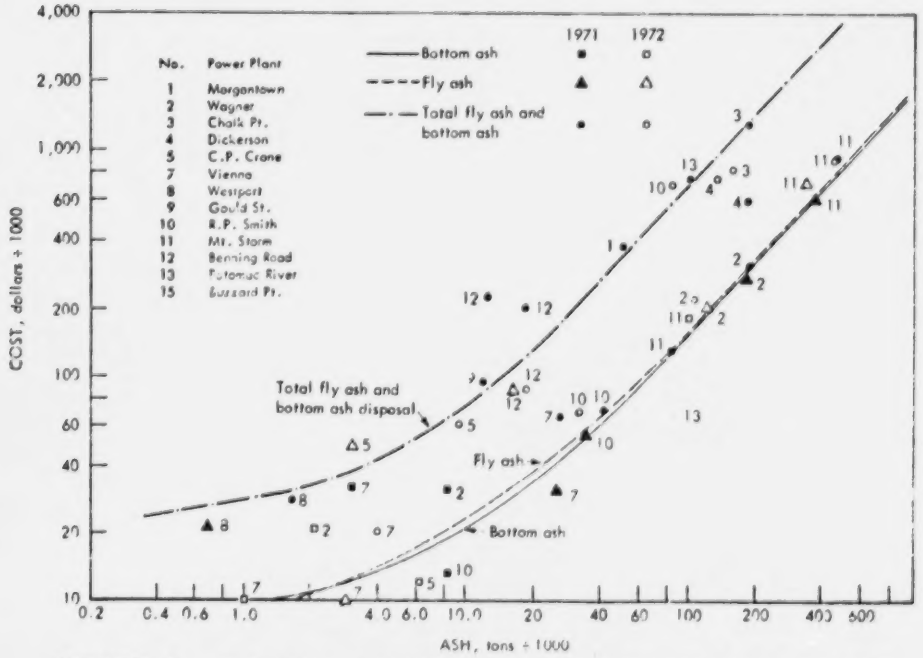


FIGURE 41 - FLY ASH , BOTTOM ASH, AND TOTAL FLY ASH AND BOTTOM ASH COLLECTION AND DISPOSAL COST FOR TWO YEARS.

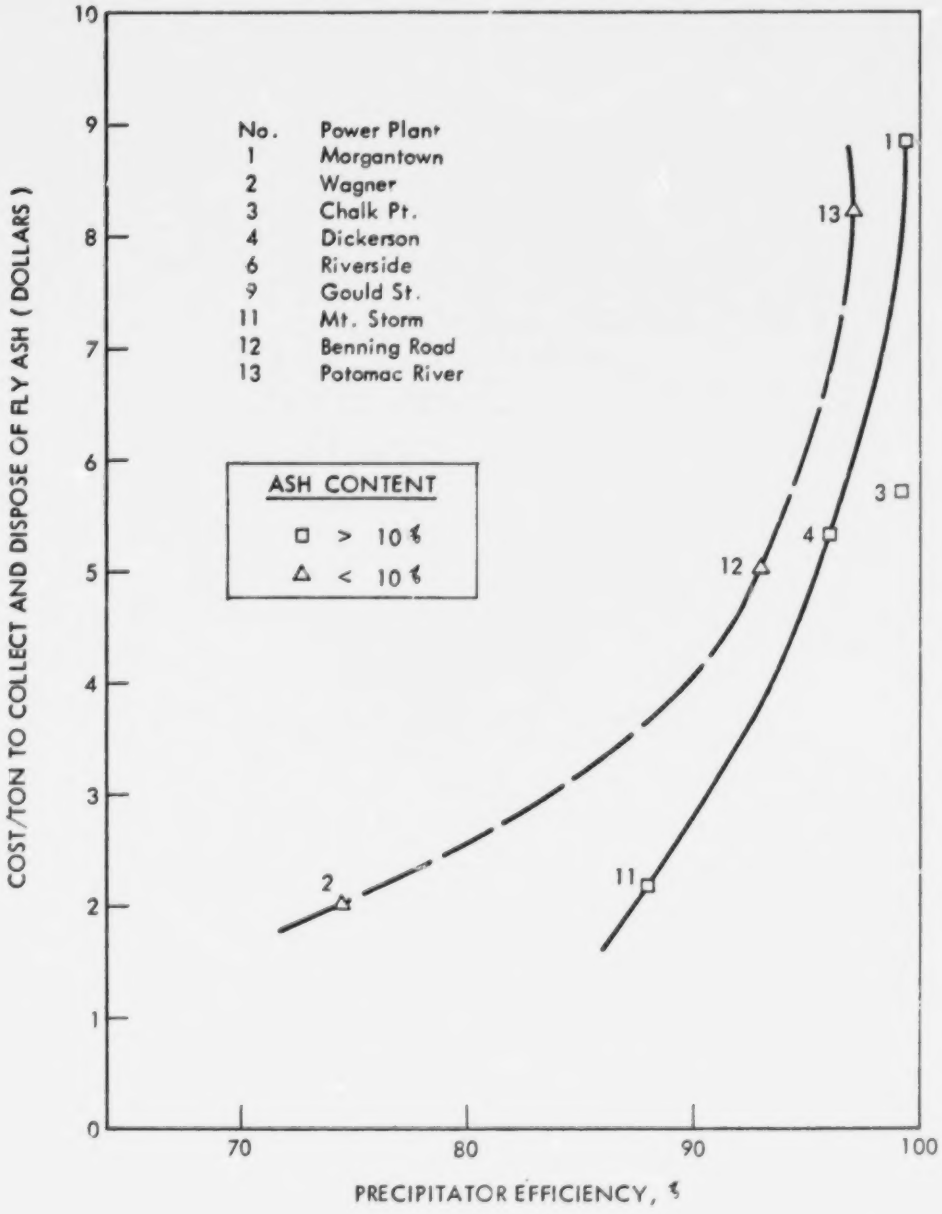


FIGURE 42 - PRECIPITATOR EFFICIENCY AND ASH CONTENT AS INFLUENCING FACTORS IN THE COST OF COLLECTION AND DISPOSAL COST OF FLY ASH

treatment can also be interpreted to mean merely that the effluent is reduced to a state where it meets certain specified water quality criteria. The former meaning is more akin to a "zero discharge" criterion, and assessments based on this meaning are outside the scope of the present study. To make assessments based on the latter definition, the criteria must themselves be first considered.

The problem of characterizing the discharges from a power plant are by no means straightforward or noncontroversial, since the characterization must bear some relationship to the ultimate impact of the discharges on the receiving waters. In the past, the thermal discharges from a power plant have been characterized in terms of the temperature of the discharges relative to that of the receiving water or in terms of the total heat that is rejected into the environment. The former parameter is of relevance in determining the direct thermal effects on aquatic organisms in the immediate vicinity of the outfall (where a thermal plume will exist), while the latter parameter governs the impact over much larger spatial and temporal scales[49]. The long-term effects should be especially of concern when discharges are made into a confined body of water such as a lake or into an estuary[50,51].

In once-through cooling, for a fixed amount of heat to be rejected, the temperature of the effluent can be reduced by using a larger quantity of circulating water. However, this does not necessarily constitute an improvement from an environmental-impact point of view, since a larger quantity of biological organisms entrained into the condenser flow are being subjected to a "thermal shock". A similar conclusion is valid for practices of reducing the discharge temperature by the use of augmentation pumping, since there is some evidence[52] that, at least under certain conditions, this practice may actually be harmful from an ecological point of view.

Recently, mechanical draft evaporative cooling towers have been recommended[19] as the "best practicable" technology currently available for controlling thermal discharges. However, by "best practicable" is meant one that would minimize environmental impact, then it is not clear that wet cooling towers would necessarily accomplish the objective at all sites and under all circumstances. Since the environment impact of power plants is likely to be strongly dependent on a number of site specific considerations, it is unlikely that a single coated procedure will be uniformly applicable to all cases. One factor that has been often overlooked is the time over which a quantity of water that is withdrawn from a water body is subjected to a higher temperature or a high chemical dosage before being discharged back to the receiving waters. Thus, while the water use by cooling towers is considerably smaller (2 to 5%) than that for once-through cooling, the time of exposure to adverse conditions is considerably higher. Hence, with cooling towers the organisms that are entrained into the intake will almost

suffer total mortality; with once-through cooling systems only a fraction of the organisms may be affected. This factor has to be evaluated for each specific site considered before decisions on the "best available" treatment can be made.

PART II

SECTION VI

STATE-OF-THE-ART AND PROGNOSIS

VI.1 GENERAL REMARKS

In the previous section engineering and economic assessments of the present state-of-the-art of power plant effluent treatment and control practices were given. A natural consequence of making such assessments is that the areas in which significant improvements in the state of the art are necessary become readily apparent. In the present section our recommendations on future research and development efforts necessary to improve power plant effluent-treatment technology are given, both from short-term and long-term points of view.

From an immediate, short-term point of view, there is a critical need for carrying out detailed engineering and economic assessments of the necessary modifications to once-through cooling systems or of backfitting power plants currently using once-through cooling with closed-cycle cooling systems from the point of view of minimizing environmental impact. As already pointed out, we do not believe that "wet" cooling towers (either natural or forced draft) necessarily constitute an universally applicable, "best available" treatment technology for minimizing environmental impact. Since detailed assessments are likely to depend on factors which are site specific and have to include ecological considerations, the tools for such assessments should be developed.

From a longer range point of view, there are needs for improvements in cooling tower technology and in the constructive uses of the "waste" heat. Regarding the latter, it is our view that in these days of energy crisis the context in which constructive uses of power plant waste heat had to be assessed is different from the traditional one. It should be noted that present and future discharge regulations imply a significant added cost to dissipate the "waste" heat. It seems inherently unsatisfactory not to utilize the added cost to derive constructive uses, rather than to use it to "throw away" potentially useful energy.

VI.2 IMPROVEMENTS IN COOLING TOWER TECHNOLOGY

In the past decade or so, there have been fairly rapid improvements in cooling-tower technology[21], the chief among these being the development of "drift-free" towers suitable for operation with brackish water and the practical application of "dry" cooling systems. While some novel design concepts have been suggested, such as the Heller system and the "stadium type" system, we do not believe that any major "breakthroughs" in cooling

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tower technology are likely to occur in the near future. System modifications and improvements will, of course, continue to be made by cooling-tower manufacturers.

In the area of the treatment of cooling-tower blowdowns, the technology for such treatment (reverse osmosis, ion exchange) seems to be available, though detailed engineering and economic assessments of their use in power plant cooling systems have not been made. There is certainly a need for such assessments.

VI.3 UTILIZATION OF WASTE HEAT AND WATER REUSE

It has often been emphasized that for effective pollution control and abatement, "man must turn from a 'throw away' economy to a 'recycling' economy"[53]. In the context of thermal pollution this implies seeking constructive uses for the large amounts of "waste" heat resulting from power generation and the integration of cooling-water usage with other water uses. In the recent literature on thermal pollution, a number of suggestions on the beneficial uses of power plant waste heat have been made[54-57]. Increasing awareness of the need for finding constructive uses for the waste heat is evidenced by the symposia that are being held devoted specifically to this subject[58]. However, while many suggestions have been made on possible beneficial uses for power-plant waste heat, critical assessments for the relative merits and demerits of the suggested uses including engineering feasibility, economic tradeoffs, and ecological and social benefits have rarely been attempted. Without such assessments, judgments or decisions on suggested beneficial uses cannot be made.

The subject of the constructive use of the "waste" heat is also timely from the point of view of currently topical subject of the energy crisis. Energy promoters have argued that the additional energy required to meet new standards for cleaning up the environment may amount to as high as 25% of the energy that is presently being used. However, as pointed out in a recent study[59] conducted for the U. S. Senate "In many cases the most intelligent approaches to these problems will be using less energy and not more. Pollution control that involves recycling or devising new uses for waste products may also lead to overall reductions in energy demands" (emphasis supplied). The study also points out that one method of reducing total energy demands is by "utilizing an increased percentage of the original energy input in a series of systems".

The primary difficulty in the utilization of power plant waste heat is that it is of a "low grade" variety; that is, the temperature difference between the waste effluents and the environment is relatively low. Nevertheless, several novel applications have been suggested and, in some cases, have actually been tried.

One of the earliest suggested beneficial uses for the waste heat was for domestic and industrial space heating[12]. The houses in the city of Farsta, near Stockholm, Sweden are heated by the waste heat from a nearby nuclear power plant[55]. Another example is the city of Tapiola in Finland[60]. Over forty percent of the population in Iceland receive their domestic heating from centralized (natural) geothermal sources[61]. In this country, steam from public utilities has been used for space heating (and cooling) for a number of industrial and commercial establishments, university campuses and groups of houses[59]. The international District Heating Association is an organization comprised of 612 electric utilities and specialty companies supplying steam alone. In the United States alone the annual consumption of steam by 18,000 customers is approximately 100,000 billion pounds ($\sim 10^{15}$ BTU), the largest single supplier being the Consolidated Edison Co. of New York.

When used in combination with electricity generation, the steam is usually discharged at some point in a steam turbine, and thus may not represent completely "waste" heat. Nevertheless, district heating offers considerable savings in overall heat units and is well suited for densely populated areas[59].

A second application that has been suggested for utilizing the waste heat is in agriculture and irrigation[2,55,62-65]. Methods that have been suggested and tried include sprinkling of crops with warm water[62-65] to prevent frost damage and prolong the growing season, and the circulation of heated water through buried pipes[64] to warm soil. It has been claimed that increases in yield of up to 66% were obtained[64], from such applications. In Iceland, greenhouses are heated by geothermal power to raise flowers and vegetables on a year-round basis[61].

Another important use for the waste heat that has been suggested is "aquaculture" or fish farming. It has been reported[55] that in Japan, which is the world's largest fishing nation, a full six percent of the total catch is by the active use of aquaculture in conjunction with over a dozen power plants along the coast of Japan. Other uses which have been suggested for utilizing power plant waste heat include deicing of roads and airport runways, creation of year-round swimming and recreational areas, sewage treatment, desalination, water purification, for dispersal, maintenance of ice-free shipping lanes and control of marine fouling. At least some of the above ideas are presently being employed to a limited extent. For example, in Kuwait and Saudi Arabia, where fresh water is at a premium, the condenser cooling water from power plants is discharged at a relatively high temperature into a seawater evaporation system to produce fresh water[57].

In all the applications mentioned earlier, the waste heat is essentially utilized for various constructive purposes in an open cycle operation.

However, the amount of waste heat that is generated by electric power plants is too great for all of it to be utilized beneficially. For example, the amount of waste heat that is currently generated is considerably in excess of the amount that is required to heat every house in the country. Thus, it appears that at least a fraction of the waste heat may have to be dissipated directly into the atmosphere. In this context, it has been suggested that for optimum use of the "waste" heat, the power plant has to be closely coupled with the selected modes of usage of the waste heat so that a closed-cycle operation, in which the same water is continuously utilized, is possible. A similar suggestion for the reuse of industrial waste water has been made by Rey, Lacy and Cywin[53].

One method by which cooling water use can be combined with other water usages seems to be integrating an electric generating plant with a sewage treatment plant. Such an integration appears to be a logical one, since in industrial societies the consumption of electricity and water go hand in hand, increasing proportionately with the standard of living[66].

There are many ways in which the integration of an electric plant and sewage-treatment plant can be accomplished. The simplest, and the most widely considered, method is to use the effluent from the sewage treatment plant as the cooling water in the power plant. This method requires the treatment of the sewage effluents at least to the teritary stage so as to minimize corrosion and fouling problems in the power plant condenser circuit. Moreover, the operation remains essentially open cycle since the waste heat is not being utilized directly, even though water usage is being minimized.

Another method which involves a nearly closed-cycle operation is based on the use of the treated sewage effluents as a make-up water for a cooling-tower system, with the "blowdown" being discharged back to the sewage treatment plant. This system also requires tertiary treatment of the sewage effluents, though in this system phosphates and nitrates are being continuously removed at the sewage treatment plant, while water is being discharged into the environment (the atmosphere) in a nearly pure form by the cooling tower. However, true closed-cycle operation is rarely possible, since at most locations the amount of treated sewage effluents available is not compatible with the amount of make-up water needed by the cooling towers.

In recent years there has been considerable interest, especially in Sweden[66], in a trinity system consisting of electricity, water and sewage plants. In such "el-wa-sew" (electricity-water-sewage) plants, a close integration of various water usages is attempted. In such systems it is recognized that, with appropriate optimizations, the treatment of the sewage effluents utilizing the power plant "waste" heat can be accomplished through multi-stage, vacuum distillation. The treated water is

itself used as cooling water in the power plant condensers, so that a large amount of water recirculation and reuse is possible.

A number of other methods of integrating a sewage treatment plant and a power plant are also possible, though these have not been considered in the literature. For example, one of the unit operations that is used at various stages of a conventional sewage treatment plant is sedimentation or gravity settling. In actual operation, the efficiencies of sedimentation devices are far lower than the theoretically obtainable maxima due to bottom stirring by inflows and outflows, and due to "basin instability"[67]. It may be possible to eliminate such deficiencies by using the power plant waste heat to create (without necessarily mixing it with the sewage) appropriate stratified flow conditions in the settling basins.

The fact that the biological processes used in conventional waste treatment are temperature dependent can also be exploited by using the power plant waste heat to accelerate these processes. For example, part of the waste heat can be used to accelerate the digestion of the sewage sludge that will result from an "el-wa-sew" trinity. Other novel methods of using the power plant waste heat for physical-chemical waste treatment have also been suggested recently[68].

However, as mentioned earlier, a critical assessment of the relative merits and demerits of the various suggested uses does not exist. Without such assessments, based on technical as well as economic considerations, judgments and decisions on the suggested uses cannot be made. For example, while a suggested use may be desirable in one specific location or under certain conditions, it may not be desirable in other locations and under different conditions.

VI. CONSTRUCTIVE USES FOR OTHER WASTE PRODUCTS

As discussed previously, coal-fueled power plants produce about 317 tons of ash per year per megawatt of power generation capacity. It was pointed out earlier, most power plants pay to have their ash disposed of. On the other hand, it appears that waste ash may have more attractive uses than being used merely as landfill. Some preliminary ideas on such constructive uses are given below, but a more detailed examination is certainly worthwhile. For example, the use of fly and bottom ash as building block materials seems to be economically feasible. An ash brick weighing 84-91 lbs/cu ft is 30% lighter than an ordinary clay brick. The normal composition of an ash brick will be 74% fine ash, 23% bottom ash and 3% sodium silicate binder[69]. Clay bricks manufactured in the Laurel, Maryland area are selling at $56-$62/1000 bricks with holes, and $95-$120/1000 bricks without holes. Present estimates of manufacturing ash bricks are

about $22/1000 bricks[69], and at 84-91 lbs/cu ft, 1000 bricks will weigh from 1.6 tons to 1.7 tons. Data relevant to the utilization of bottom and fly ash in brick manufacture are presented in Figures 43 and 44.

As mentioned earlier, waste ash also appears to be a good filtration medium. In filtration theory and practice it is well known that certain colloidal materials and clays have special filtration properties. The experience at the R. P. Smith plant seems to indicate that power plant waste ash may also have similar filtration properties. If such is the case, then it is of interest to investigate the use of the waste ash to filter cooling-tower blowdown. The use of the waste ash for filtration may also have applications in integrated-water-use systems.

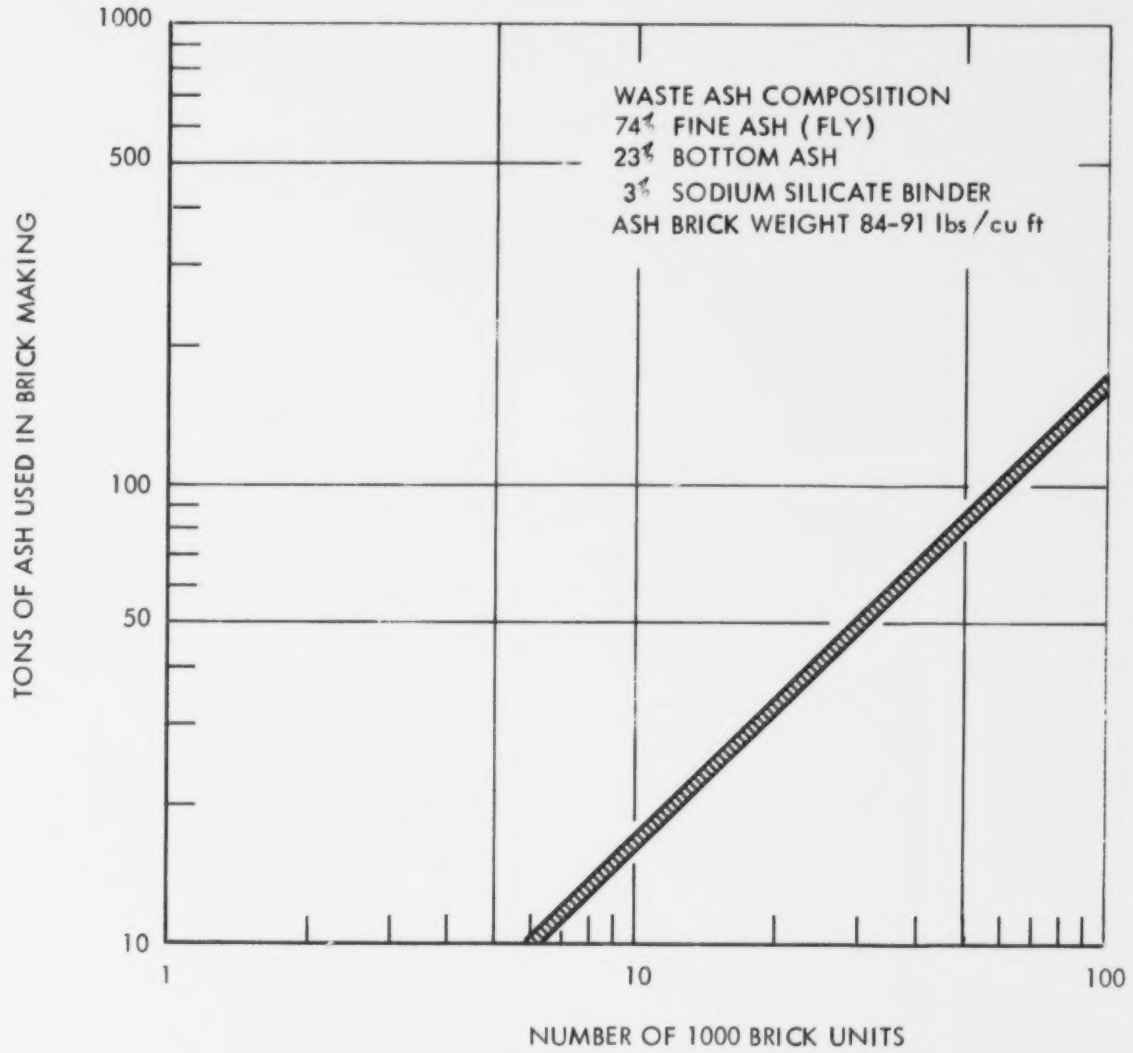

FIGURE 43 - UTILIZATION OF FLY AND BOTTOM ASH FOR BRICK CONSTRUCTION

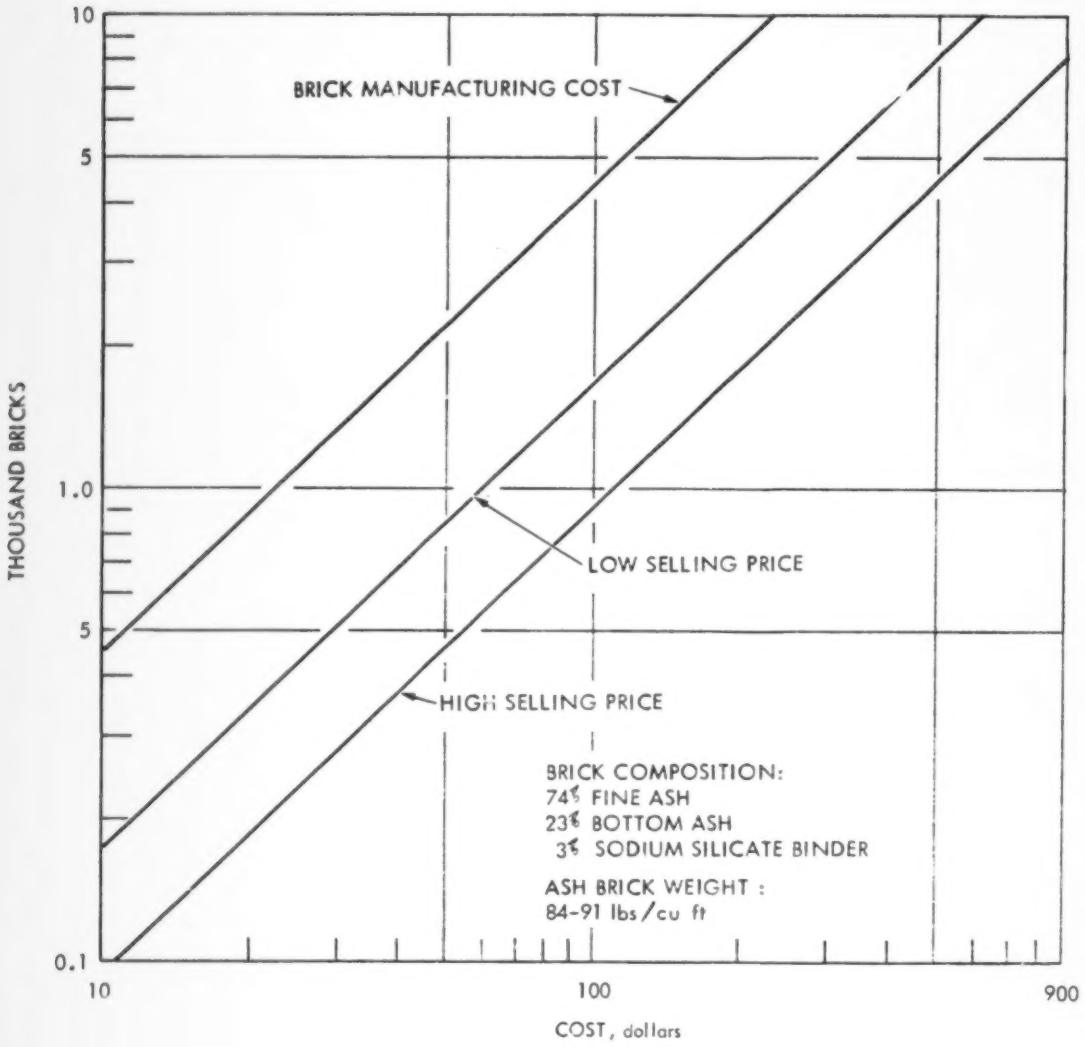

FIGURE 44 - MANUFACTURING AND SELLING PRICE FOR BRICKS CONSTRUCTED FROM POWER PLANT FLY AND BOTTOM ASH

SECTION VII

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PART III

SECTION VIII

APPENDICES

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APPENDIX A

POWER PLANT DATA SHEET

This Power Plant Data Sheet has been prepared to enable an evaluation of power plant operation and cooling techniques. The data sheet is divided into the following categories which, it is hoped, will make completion easier:

Section 1 - General Background Statistics of the Power Plant

Section 2 - Cooling Information

Section 3 - Chemical Analysis of Make-Up, Blowdown, Corrosion-inhibitors, and Anti-foulants

Section 4 - Fly Ash Disposal

Section 5 - Engineering Assessments

Section 6 - Waste Water from Non-cooling Sources

Section 7 - Economic Considerations

The assessment of this questionnaire is part of a program to evaluate the State-of-the-Art of Engineering Aspects of Power Plant Thermal Discharges.

Name of Power Utility _____

Location _____

_____

The information supplied for this Power Plant Data Sheet is representative of the year _____

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1. GENERAL BACKGROUND STATISTICS OF THE POWER PLANT

1.1 What year did the power utility begin operation?_____

1.2 What is the rated peak capacity (megawatts)?_____

1.3 What is the energy source (nuclear, coal, oil, gas, hydroelectric)?

_____

1.4 What is the efficiency of the plant?_____

_____

1.5 Is any waste heat or steam sold for industrial or commercial use?

_____

1.6 Is supplementary equipment employed during peak load periods?_____

_____

1.7 Total heat rejected 10^8 BTU/HR_____

1.8 What is the maximum condenser flow?_____

1.9 Location of Power Plant:

Latitude_____ Longitude_____

1.10 Distance from nearest city?_____

1.11 Name of city?_____

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2. COOLING INFORMATION

2.1 What is the cooling method utilized (once-through, spray or cooling pond, cooling towers)?_____

2.2 If a cooling tower is used, what type of cooling tower method is utilized (natural, atmospheric, forced or induced draft, cross or counter flow)?_____

2.3 If once-through cooling is used, what type of outfall and diffuser is utilized (i.e., discharge canal, multiport diffuser, etc.)?_____

2.4 What is the incremental temperature increase of the cooling water after leaving the condenser?_____

2.5 What is the peak cooling flow in million gallons per day?_____

2.6 What is the peak cooling water heating in BTU's/day?_____

2.7 Is the cooling water considered fresh, salty or brackish?_____

2.8 What is the optimum atmospheric temperature for best performance, based on experience?_____

2.9 What is the optimum relative humidity for best performance, based on experience?_____

2.10 What is the optimum wind-velocity for best performance, based on experience?_____

2.11 How many times is the cooling water recycled?_____

2.12 What is the amount of make-up water in million gallons per day?_____

2.13 What is the thermal loading of blowdown?_____

2.14 What is the size of the cold water basin?_____

2.15 What is the average depth of the cooling basin?_____

2.16 How often is the cold water basin of the cooling tower cleaned?_____

2.17 How much water is used to clean the cold water basin?_____

2.18 What is the source of the cold water basin cleaning water?_____

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2.19 How is the cleaning water disposed of?_____

_____

2.20 What is the chemical analysis and pH of the cleaning water at the end of the cleaning process?_____

_____

2.21 How is the cooling tower blowdown disposed of?_____

_____

2.22 What type of packing is used in the cooling tower?_____

_____

2.23 What is the packing material made from?_____

_____

2.24 For once-through cooling, what is the source of water?_____

_____

2.25 Water source, for once-through cooling, has an available supply of water that is _____ million gallons per day.

2.26 When using a once-through cooling system, is any consideration made for those people, industries, or utilities that are located farther down river?_____

_____

2.27 What is the volume of the cooling pond in acre-ft?_____

_____

2.28 What is the area of the cooling pond in acres?_____

2.29 What is the average depth of the cooling pond?_____

2.30 Width of river near discharge?_____

2.31 Average depth near discharge?_____

2.32 Typical low flow in the fall?_____

2.33 Typical high flow in the spring?_____

2.34 What is the summer daily maximum air temperature?_____

2.35 What is the winter daily maximum air temperature?_____

		Average	Maximum	Minimum
2.36	Air temperatures	_____	_____	_____
2.37	Dew point temperature	_____	_____	_____
2.38	Wind speed	_____	_____	_____
2.39	Solar radiation	_____	_____	_____
2.40	What is the intake temperature?	_____	_____	_____
2.41	What is the discharge temperature?	_____	_____	_____
2.42	What is the condenser flow?	_____	_____	_____
2.43	Tidal amplitude	_____	_____	_____
2.44	Volume of upstream tidal prism	_____	_____	_____

3. CHEMICAL ANALYSIS OF MAKE-UP, BLOWDOWN, CORROSION-INHIBITORS AND ANTI-FOULANTS

3.1 Make-up

3.1.1 What is the pH of the water?_____

3.1.2 What is the salinity (ppm) of the water?_____

3.1.3 What is the temperature of the make-up water?_____ _____

3.1.4 What is the Ca hardness (ppm)?_____

3.1.5 What is the M alkalinity (ppm)?_____

3.1.6 What is the total dissolved solids (ppm)?_____

3.1.7 Is sulfuric acid used to maintain a pH level?_____

3.1.8 What is the Langelier index?_____

3.1.9 What is the ambient water source temperature?_____

3.1.10 What is the sulfate constituent as SO_4 (ppm)?_____

3.1.11 What is the calcium constituent as $CaCO_3$ (ppm)?_____

3.1.12 What is the magnesium constituent as $CaCO_3$ (ppm)?_____

_____

3.1.13 What is the chloride constituent as Cl (ppm)?_____

3.1.14 What is the sodium constituent as Na (ppm)?_____

	Average	Maximum	Minimum
3.1.15 What is make-up pH?	_____	_____	_____
3.1.16 Month(s) of maximum pH?	_____	_____	_____
3.1.17 Month(s) of minimum pH?	_____	_____	_____

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3.2 Corrosion-inhibitors and Anti-foulants

3.2.1 Name(s) of corrosion-inhibitor(s) used in cooling water?_____

_____

3.2.2 Amount of corrosion-inhibitor(s) used to maintain a low level of corrosion?_____

3.2.3 Name(s) of anti-foulant agent(s) used in cooling water?_____

_____

3.2.4 Amount of anti-foulant agent(s) used to maintain a low level of fouling?_____

3.2.5 Frequency of use of corrosion-inhibitor(s) in make-up water?____

_____

3.2.6 Concentration of corrosion-inhibitors in make-up water?_____

_____

3.2.7 Frequency of use of anti-foulant(s) in make-up water?_____

_____

3.2.8 Concentration of anti-foulant agent(s) in make-up water?_____

_____

3.2.9 Do you have any comments to make regarding other corrosion-inhibitors or anti-foulants? Please describe any experience with any other corrosion-inhibitor or anti-foulant. _____

_____

_____

_____

_____

3.2.10 How rapidly does packing material deteriorate?_____

_____

3.2.11 What rationale is used to determine the dosage and frequency of use of biocides and bacteriocides?_____

_____

_____

_____

_____

_____

3.3 Blowdown

3.3.1 Characterize blowdown in terms of chemical inhibitors and pH_____

_____

_____

_____

_____

_____

3.3.2 Is a water recovery attempt made?_____

_____

_____

3.3.3 How is blowdown disposed of?_____

_____

3.3.4 Is any attempt made to treat blowdown prior to discharge?_____

_____

_____

3.4 Boiler Blowdown Settling Pond

	Pond 1	Pond 2
3.4.1 Method of cleaning	_____	_____
3.4.2 Frequency of cleaning	_____	_____
3.4.3 pH	_____	_____
3.4.4 Suspended solids	_____	_____
3.4.5 Salinity	_____	_____
3.4.6 Ca Hardness (ppm)	_____	_____
3.4.7 M Alkalinity (ppm)	_____	_____
3.4.8 Calcium as $CaCO_3$ (ppm)	_____	_____
3.4.9 Magnesium as $CaCO_3$ (ppm)	_____	_____
3.4.10 Chloride (ppm)	_____	_____
3.4.11 Sodium (ppm)	_____	_____
3.4.12 SO_4 (ppm)	_____	_____
3.4.13 Discharge volume	_____	_____
3.4.14 Receiving body	_____	_____

3.5 Bottom Ash Settling Pond

		Pond 1	Pond 2
3.5.1	Method of cleaning	_____	_____
3.5.2	Frequency of cleaning	_____	_____
3.5.3	pH	_____	_____
3.5.4	Suspended solids	_____	_____
3.5.5	Salinity	_____	_____
3.5.6	Ca Hardness (ppm)	_____	_____
3.5.7	M Alkalinity (ppm)	_____	_____
3.5.8	Calcium as $CaCO_3$ (ppm)	_____	_____
3.5.9	Magnesium as $CaCO_3$ (ppm)	_____	_____
3.5.10	Chloride (ppm)	_____	_____
3.5.11	Sodium (ppm)	_____	_____
3.5.12	SO_4 (ppm)	_____	_____
3.5.13	Discharge volume	_____	_____
3.5.14	Receiving body	_____	_____
3.5.15	Amount of ash treated	_____	_____

3.6 Stack Water Settling Pond

		Pond 1	Pond 2
3.6.1	Method of cleaning	_____	_____
3.6.2	Frequency of cleaning	_____	_____
3.6.3	pH	_____	_____
3.6.4	Suspended solids	_____	_____
3.6.5	Salinity	_____	_____
3.6.6	Ca Hardness (ppm)	_____	_____
3.6.7	M Alkalinity (ppm)	_____	_____
3.6.8	Calcium as $CaCO_3$ (ppm)	_____	_____
3.6.9	Magnesium as $CaCO_3$ (ppm)	_____	_____
3.6.10	Chloride (ppm)	_____	_____
3.6.11	Sodium (ppm)	_____	_____
3.6.12	SO_4 (ppm)	_____	_____
3.6.13	Discharge volume	_____	_____
3.6.14	Receiving body	_____	_____
3.6.15	Amount of ash treated	_____	_____

3.7 Cooling Water Blowdown Settling Pond

		Pond 1	Pond 2
3.7.1	Method of cleaning		
3.7.2	Frequency of cleaning		
3.7.3	pH		
3.7.4	Suspended solids		
3.7.5	Salinity		
3.7.6	Ca Hardness (ppm)		
3.7.7	M Alkalinity (ppm)		
3.7.8	Calcium as $CaCO_3$ (ppm)		
3.7.9	Magnesium as $CaCO_3$ (ppm)		
3.7.10	Chloride (ppm)		
3.7.11	Sodium (ppm)		
3.7.12	SO_4 (ppm)		
3.7.13	Discharge volume		
3.7.14	Receiving body		

3.8 Sewage Disposal

		Before Treatment	After Treatment
3.8.1	BOD	_____	_____
3.8.2	pH	_____	_____
3.8.3	Phosphate (ppm)	_____	_____
3.8.4	Other:		
	_____	_____	_____
	_____	_____	_____
	_____	_____	_____
	_____	_____	_____
	_____	_____	_____
	_____	_____	_____

3.8.5 Discharge body _____

3.8.6 What is used to reduce phosphates? _____

4. FLY ASH DISPOSAL

4.1 What type of coal is used?_____

4.2 What is the thermal potential of the coal (BTU/LB)?_____

4.3 What is the sulfur content of the coal?_____

4.4 How much coal is used per day?_____

4.5 How much ash is disposed of in lbs/day?_____

4.6 What is the method of ash disposal?_____

4.7 Is the fly ash put to any good use, if so what?_____

_____

4.8 Amount of water used for stack scrubbing in gallons per day?_____

_____

4.9 What is the source of scrubbing water?_____

_____

4.10 How is the stack scrubbing water disposed of?_____

_____

4.11 What is the characterization and pH of stack scrubbing water?_____

_____

4.12 What is the cost, in cents/1000 gallons, of the stack scrubbing water?_____

4.13 Comments about scrubbing water?_____

_____

_____

_____

_____

_____

_____

_____

5. ENGINEERING ASSESSMENT

5.1 What is the drift loss in gallons per day?_____

5.2 What percent of power load, in excess of design capacity can the cooling tower handle in off-design operation?_____

_____

5.3 How much down time is experienced due to corrosion and fouling problems?_____

5.4 What kind of treatment does blowdown undergo?_____

_____

5.5 If using a cooling tower, how often does fogging conditions occur?

_____

5.6 How often do severe fogging conditions occur?_____

_____

5.7 How often does icing occur in the winter?_____

5.8 Describe the plume that most often emanates from the cooling tower?_____

_____

_____

_____

5.9 Does this plume most often rise and merge with the overhead clouds or sink and cause fogging problems?_____

_____

5.10 Does the plume often disappear before reaching the ground?_____

_____

5.11 The noise levels caused by the power utility would be described as high, medium, low?_____

5.12 The distance between power plant and the nearest residential area? _____(miles).

5.13 How often does the power plant receive calls of complaint about the noise level of the utility?_____

5.14 How often does the power plant receive complaints about the fogging of nearby roads?_____

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5.15 Has the community surrounding the power plant accepted the presence of the power utility?_____

5.16 How big is the residential area? (Population)_____

5.17 What is the noise level 1000 yards away from the cooling tower?

_____db.

5.18 What is the noise level 2000 yards away from the cooling tower?

_____db.

5.19 What are the water pump power requirements?_____

_____

5.20 What are the fan motor power requirements?_____

_____

6. WASTE WATER FROM NON-COOLING SOURCES

6.1 Amount of boiler blowdown (gallons per day)?_____

6.2 What is the character and pH of boiler blowdown?_____

_____

6.3 What is the method of disposal of boiler blowdown?_____

_____

6.4 What is the frequency of boiler blowdown?_____

6.5 What criterion is used to determine when to blowdown the boiler?

_____

6.6 What is the cleaning fluid used?_____

6.7 Are solutes like hydrazine added?_____

6.8 How is the air heater cleaned?_____

6.9 What demineralizers are used?_____

6.10 Is any provision made for water recovery?_____

_____

7. ECONOMIC CONSIDERATIONS

7.1 Cost per KWH to operate a cooling tower?_____

7.2 Cost per KWH for once-through cooling?_____

7.3 Cost per 1000 gallons of cooling water? _____

7.4 Cost per 100 pounds of chemical inhibitor(s) and anti-foulant agent(s)?_____

7.5 Cost of treatment of cooling tower make-up water (cents/1000 gallons)?_____

7.6 Cost of treatment of cooling tower blowdown water (cents/1000 gallons)?_____

7.7 Cost of maintenance of the cooling tower?_____

7.8 Number of man-hours per year spent on maintenance?_____

_____

7.9 Cost of treating stack scrubbing water (cents/1000 gal)?_____

_____

7.10 Cost of treating boiler blowdown water (cents/1000 gal)?_____

_____

7.11 If blowdown is stored in holding ponds, what is the cost per 1000 gallons?_____

7.12 Any further remarks you would like to make?_____

_____

_____

_____

_____

_____

_____

7.13 Capital cost per KWH to construct cooling tower or pond?_____

_____

7.14 Does the capital cost include installation of pipe, electrical wires, and site preparation?_____ _____

7.15 Cooling water system annual operating and maintenance cost?_____

_____

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7.16 Cooling water system annual chemical additive cost? _____

_____

7.17 Boiler water make-up and blowdown annual operating and maintenance cost? _____

7.18 Boiler water make-up and blowdown annual chemical additive cost?

_____

APPENDIX B

POWER PLANT INFORMATION SHEETS

A

TABLE 1 - "POWER PLANT INFORMATION S

SECTION A - Selected Powe																			
															COAL				
UTILITY / OPERATING / PLANT / WEB	Reference Number	Data From Year	Year Plant Commenced Operation	Year Newest Unit Commenced Operation	Age of Newest Unit	Age of Plant	Installed Capacity - MW	Normal Operating Capacity - MW	Energy Source	Plant Efficiency	Supplementary Equipment Used During Peak Load Periods	Waste Heat Sold for Commercial Use	INTERVENTION	Coal Consumption - 1000 Tons/Year	Heat Capacity - BTU/Lb.	Sulfur Content - %	Ash Content - %	Oil Consumption - 1000 Bbls/Year	Heat Capacity BTU/GAL.
Morgantown (PEPCO)	1	1972	1970	1971	2	3	1,309.0	1,148.0	C/O	37.0	No	No		615.6	12,719	1.98	14.19	7640.9	148,24
Wagner (BG&E)	2	1972	1966	1972	1	17	900	487	C/O	38.9	Yes	No		840	13,018	<1.00	9.6	8742.2	146,21
Chalk Pt. (PEPCO)	3	1972	1964	1965	8	9	730	730	C	35.0	No	No		1,027	12,467	1.7	12.4	0	-
Dickerson (PEPCO)	4	1972	1959	1962	11	14	570	570	C	31.0	No	No		1,030	12,896	1.8	13.3	0	-
Crane, C.P. (BG&E	5	1972	1961	1963	10	12	386	386	C/O	36.9	Yes	No		140.7	13,411	4.29	7.8	2880.49	145,72
Riverside (BG&E	6	1972	1940	1963	20	31	322	313	O	33.2	Yes	No		0	-	-	-	2584.1	146,15
Vienna (DELMARVA	7	1972	1937	1971	2	46	245.6	245.6	C/O	28.8	Yes	No		91.7	12,867	0.99	10.12	1922.0	146,00
Westport (BG&E)	8	1972	1902	1950	23	71	144	173	O	31.6	Yes	No		0	-	-	-	1441.4	145,92
Gould St. (BG&E)	9	1972	1936	1952	21	47	150	150	O	31.6	Yes	No		0	-	-	-	1438.9	145,91
R. P. Smith (APCO)	10	1972	1943	1948	16	50	129	140	C	31.6	No	No		256	12,035	1.32	12.6	0	-
SECTION B - Selected Power Plant																			
Mt. Storm (VEPCO)	11	1972	1965	1966	7	8	1140.5	1,140.5	C	-	Yes	-		5,762.5	11,967	2.03	10.23	0	-
Benning Pt. (PEPCO)	12	1972	1906	1968	5	67	751	751	C/O	-	-	-		176.8	13,148	0.8	9.1	3646.3	146,22
Potomac River (PEPCO)	13	1972	1949	1957	16	24	515	514	C/O	-	-	-		967.3	13,363	0.86	9.9	36.4	138,13
Possum Pt. (VEPCO)	14	1972	1948	1962	11	25	491	491	O	-	Yes	-		0	-	-	-	5048.6	148,41
Buzzard Pt. (PEPCO)	15	1972	1933	1945	28	40	305	305	O	-	-	-		0	-	-	-	1069.2	146,04

KEY: Fuel Source - C/O = Coal/Oil
C = Coal
O = Oil

INFORMATION SHEET" ON FUEL AND WASTE PRODUCTS

Ash Content - %	Oil Consumption +1000 Bbls/Year	Oil		Combustion Waste Disposal Facilities and Utilization Arr. Utilized	Fly Ash Collected +1000 Tons	Bottom Ash Collected +1000 Tons	Land Fill Disposal of Fly and Bottom Ash +1000 Tons	Amount of Ash Sold +1000 Tons	Ash Selling Price +$/ton	Cost of Collection and Disposal +$/ton			Flue Gas Treating Equipment	Flue Cleaning Equipment		Boat Precipitator Unit Estimated Efficiency at Annual Operating Factor	Average of Precipitator Units Estimated Efficiency At Annual Operating Factor
		Heat Capacity BTU/Gal.	Sulfur Content - %							Fly Ash	Bottom Ash	Total Ash		Electrostatic Precipitator	Mechanical Precipitator		
14.19	7640.9	148,248	1.98		78.3	.7	87.1	0	0	0	-	-	699.6		x		99.8	99.8
9.6	3742.9	146,211	0.9		119.6	8.1	107.7	72	8	6.4	333.1	20.2	253.3		x	x	96.0	74.8
12.4	0	-	-		144.9	16.0	160.3	0	0	0	-	-	833.0		x		99.6	99.1
13.3	0	-	-		160.4	16.7	167.1	0	0	0	-	-	730.0		x		98.2	98.2
7.8	2880.49	146,720	0.83		8.2	6.2	8.2	0	6.2	4.4	56.0	14.0	60.9		x		63.3	63.3
-	2884.1	146,153	0.9		-	-	0.017	0	0	0	24.6	13.7	38.3		x		78.7	78.8
10.12	1839.0	146,000	0.91		8.0	1.0	0	4	0	4	19.0	13.0	32.0		x	x	-	-
-	1441.4	145,324	0.9		0	0	0	0	0	0	31.6	13.7	45.3		x	x	80.0	72.0
-	1439.9	145,312	0.9		-	-	0.029	0	0	0	10.6	2.6	13.1		x		60.0	60.0
12.6	0	-	-		-	-	30.1	0	0	0	40.7	13.0	53.7		x		-	-
B - Selected Power Plants, Located in the Maryland Region																		
18.23	0	-	-		382.0	100.0	482.0	0	0	0	715.3	134.7	850.0		x		90.0	88.1
9.1	3566.3	146,226	0.9		17.0	2.0	19.0	0	0	0	86.6	0	86.6		x	x	93.0	93.0
9.3	36.5	138,137	0.12		81.2	9.0	90.2	0	0	0	-	-	67.3		x	x	98.2	97.2
-	5048.6	148,417	2.27		0	0.1	0.1	0	0	0	0	27.4	27.4		x		72.0	72.0
-	1069.2	146,045	0.98		0.00008	0	0.00008	0	0	0	40.0	0	40.0		x	x	90.0	90.0

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A

TABLE 2 - "POWER PLANT INFORMATION SHEET" ON COOLIN

SECTION A - Power Plants, with a Generating Capacity Greater than
Thermal Effluent Discharges, Located within the State

POWER PLANT	Reference Number	Report Year	Plant Capacity (MW) Utilizing:			Total Installed ($) Cost:			Average Annual Rate of Water			Reported Peak Cooling Flow:			Character of Cooling Flow	Temper Across
			Normal (Installed Capacity (MW))	Waste Heat (Btu/hr) at Peak Loading x 10^9 BTU/HR	COOLING SYSTEM INFORMATION	Cooling Method(s) Employed by the Power Plants	Once-through Cooling	Cooling Towers	Cooling Ponds	Once-through Cooling ($ 1000)	Cooling Towers ($ 1000)	Cooling Ponds ($ 1000)	Withdrawal - CFS	Discharge - CFS	Consumption - CFS	Once-through Cooling - CFS	Cooling Tower - CFS	Cooling Pond - CFS		Average - ^{o}F.
Morgantown	1	1972	1148.0	46.8		T	1148.0	-	-	[illegible]	-	-	2070.0	2070.0	0	2070.0	-	-	R	8.8
Wagner	2	1972	980.0	39.1		T	980.0	-	-	[illegible]	-	-	1006.0	1006.0	0	854.0	-	-	R	15.0
Chalk Point	3	1972	750.0	45.8		T	750.0	-	-	[illegible]	-	-	697.0	697.0	0	697.0	-	-	R	11.0
Dickerson	4	1972	800.0	34.6		T	800.0	-	-	[illegible]	-	-	608.0	608.0	0	608.0	-	-	R	16.0
Irvine, C. E.	4	1972	586.0	23.0		T	586.0	-	-	1[illegible]	-	-	636.0	636.0	0	350.0	-	-	R	11.3
Riverside	6	1972	919.0	31.7		T	919.0	-	-	1[illegible]6	-	-	486.0	486.0	0	486.0	-	-	R	15.5
Vienna	7	1972	218.0	22.0		T/Pond	97.0	121	-	7[illegible]	4[illegible]9	-	221.0	218.5	2.5	1[illegible]	47	-	R	10.0
Westport	8	1972	171.0	10.8		T	171.0	-	-	10[illegible]	-	-	393.0	393.0	0	393.0	-	-	R	10.0
South Street	9	1972	120.0	11.1			120.0	-	-	[illegible]	-	-	835.0	835.0	0	835.0	-	-	R	11.0
[illegible] Point	10	1972	1.0	5.2		T	1.0	-	-	[illegible]	-	-	164.0	164.0	0.1	164.0	-	-	R	18.0
SECTION B - Selected Power Units Located in the Maryland																				
T. Thom	11	1972	114.0	7[illegible]		[illegible]	-	-	11[illegible]	-	-	[illegible]	112[illegible]	112[illegible]	1.3	[illegible]	-	11	R	19.3
Cooling Pond	12	1972	70[illegible]	9[illegible]		T/Pond	1[illegible]	[illegible]	-	9[illegible]	[illegible]	-	[illegible]	[illegible]	3.0	[illegible]	[illegible]	-	F	19.1
Potomac River	13	1972	710.0	38.[illegible]		T	710.0	-	-	1[illegible]11	-	-	69[illegible]	69[illegible]	[illegible]	69[illegible]	-	-	F	18.0
Potomac River	14	1972	548.1	31.8[illegible]		T	548.1	-	-	1[illegible]701	-	-	461.[illegible]	4[illegible].1	0.3	4[illegible].0	-	-	F	19.5
Morgard River	15	1972	998.0	31.0[illegible]		T	998.0	-	-	1[illegible]69[illegible]	-	-	8[illegible].0	8[illegible].0	0	8[illegible].0	-	-	F	9.0

CHY: E = Estimated
NI = No Information
B = Brackish
F = Fresh
T = Tidal

Cooling Methods: T = Once-through cooling
CT = Cooling tower
WCT = With cooling tower
CP = Cooling pond

B

LANT INFORMATION SHEET" ON COOLING SYSTEMS

SECTION A - Power Plants, with a Generating Capacity Greater ..... 100 MW and Thermal Effluent Discharges, Located within the State of Maryland

Average Annual Rate of Water			Reported Peak Cooling Flow:			Character of Cooling Water	Temperature Rise across Condenser:			Condenser Intake Temperature:			Condenser Discharge Temperature			Annual Net Fresh Water Use			Thermal Unit Discharge - BTU's/Year	Thermal Load Discharge - BTU's/Year
Withdrawn CFS	Discharge CFS	Consumption - CFS	Freshwater Cycle - CFS	Coastal Tower - CFS	Coastal Pond - CFS		Average - Δt_a	Maximum - Δt_x	Minimum - Δt_n	Average - t_a	Maximum - t_x	Minimum - t_n	Average - t_a	Maximum - t_x	Minimum - t_n	Average - MG x 1000	Maximum - MG x 1000	Minimum - MG x 1000		
2070.0	2070.0	0	2070.0	-	-	S	9.8	11.3	9.1	75	81	76	85	88	85	1	1	1	1	1
1006.0	1006.0	0	895.0	-	-	S	14.3	15.3	13.3	76	81	78	93	96	91	1	1	1	1	1
697.0	697.0	0	697.0	-	-	S	11.3	13.3	9.3	81	87	80	100	104	93	-	-	-	.83	1.3
638.0	638.0	0	638.0	-	-	S	16.0	16.3	15.3	81	86	84	97	102	98	-	-	-	.9	1.4
636.0	636.0	0	636.0	-	-	S	11.5	13.3	11.3	78	84	81	89	97	92	1	1	1	1	1
486.0	486.0	0	486.0	-	-	S	1.0	14.0	1.0	76	83	77	77	97	78	1	1	1	1	1
220.0	213.0	5.5	17.0	40	-	S	10.0	15.	9.0	77	84	78	87	104	87	1	1	1	1	1
353.0	353.0	0	353.0	-	-	S	11.3	17.3	10.3	82	91	83	93	110	93	1	1	1	1	1
337.0	337.0	0	337.0	-	-	S	1.3	15.3	1.3	77	85	78	87	97	87	1	1	1	1	1
161.0	161.0	0.1	161.0	-	-	S	1.3	15.	10.3	75	83	76	84	100	86	.5	1.0	.5	.5	.5

SECTION B - Selected Power Plants Located in the Maryland Coastal Zone

1126.0	1126.0	1.0		-	11	S	13.5	15.	12.5	75	83	76	89	98	89	-	-	-	-	-
697.0	694.0	3.0	535.0	40	-	S	13.1	15.	11.1	75	85	76	88	100	87					
697.0	697.0	0	697.0	-	-	S	11.3	13.	10.3	80	86	79	91	99	89					
561.0	560.8	5.3	555.0	-	-	S	10.0	12.3	14.3	80	87	83	90	103	97	19.3	19.	11.1	11.	11.
239.0	239.0	0	239.0	-	-	S	9.3	9.3	9.	75	84	79	84	93	88	1	1	1	1	1

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TABLE 3 - "POWER PLANT INFORMATION SHEET" ON COOLING SYSTEM (Continued)

POWER PLANTS	Reference Number	Reported Year	ONCE-THROUGH COOLING	Water Body Receiving Discharge	Width of River Near Discharge - Ft.	Average Depth Near Discharge - Ft.	Average Tidal Amplitude - Ft.	Plants Employing Discharge Canals	COOLING TOWERS	Type of Cooling Towers	Type of Air Flow	Range °F.	Area of Cold Water Basin (Sq.Ft.)	Average Depth of Cold Water Basin -Ft.	Packing Material	Frequency of Cleaning Cold Water Basin (Times/Year)	Method of Cleaning Cold Water Basin	Source of Cold Water Basin Cleaning Water	Cold Water Basin Cleaning Water Disposal Method	COOLING POND	Cooling Pond Surface Area (acres)	Average Depth of Cooling Pond (Ft.)
SECTION A - Selected Power Plants Within the State of Maryland																						
Morgantown	1	1972		P	NI	NI	NI	X		-	-	-	-	-	-	-	-	-	-		-	-
Wagner	2	1972		PGT	10,550	1.5	4	X		-	-	-	-	-	-	-	-	-	-		-	-
Chalk Point	3	1972		PAT	5,200	NI	2	-		-	-	-	-	-	-	-	-	-	-		-	-
Dickerson	4	1972		P	600	8	-	X		-	-	-	-	-	-	-	-	-	-		-	-
Crane, C. P.	5	1972		SP	1,320	NI	4	X		-	-	-	-	-	-	-	-	-	-		-	-
Riverside	6	1972		PGT	3,000	NI	4	X		-	-	-	-	-	-	-	-	-	-		-	-
Vienna	7	1972		NAN	1,000	15	2	X		MF	CF	20	7,457	5	Plastic	1	Shoveling and Hosing	NAN	Recycled in Cooling Tower		-	-
Westport	8	1972		PGT	2,240	NI	3	X		-	-	-	-	-	-	-	-	-	-		-	-
Gould St.	9	1972		PGT	1,280	NI	4	X		-	-	-	-	-	-	-	-	-	-		-	-
R. P. Smith	10	1972		P	700	3	0	X		-	-	-	-	-	-	-	-	-	-		-	-
SECTION B - Selected Power Plants Located in the Maryland Region																						
Mt. Storm	11	1972		-	-	-	-	-		-	-	-	-	-	-	-	-	-	-		NI	NI
Benning Road	12	1972		A	NI	2	NI	-		M	NI	24	NI	NI	NI	NI	NI	NI	NI		-	-
Potomac River	13	1972		P	NI	NI	NI	-		-	-	-	-	-	-	-	-	-	-		-	-
Possum Point	14	197-		P	NI	NI	NI	-		-	-	-	-	-	-	-	-	-	-		-	-
Buzzard Point	15	1972		A	NI	10	NI	-		-	-	-	-	-	-	-	-	-	-		-	-

KEY: Water Bodies:
P = Potomac River
PAT = Patuxent River
PGT = Patapsco River
A = Anacostia River
SP = Salt Peter Creek
NAN = Warticoke River

NI = No Information

Cooling Towers:
MF = Mechanical Forced Draft
CF = Cross Flow

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TABLE 4 - "POWER PLANT INFORMATION SHEET" ON COST OF OPERA
AND CHEMICAL ADDITIONS TO BOILER AND COOLING WA

POWER PLANT	Reference Number	Reported Year	Peak Generating Plant - MW	COOLING WATER SYSTEM	Annual Operating and Maintenance Cost + $1000	Annual Cost of Chemical Additions + $1000	Total Annual Cost + $1000	CHEMICALS ADDED TO COOLING WATER	Caustic Soda - Lbs. + 1000	Alum - Lbs. + 1000	Chlorine - Lbs. + 1000	Sodium Dichromate - Lbs. + 1000	Sulfuric Acid - Gals. + 1000	Hydrazine - Lbs. + 1000	Calcium Hypochlorite - Lbs. + 1000	BOILER WATER SYSTEM	MAKE-UP AND BLOWDOWN: Annual Operation and Maintenance Cost + $1000	MAKE-UP AND BLOWDOWN: Annual Chemical Additive - Cost + $1000	MAKE-UP AND BLOWDOWN: Total Annual Cost + $1000	CHEMICALS ADDED TO BOILER WATER	Phosphate - Lbs. + 1000	Caustic Soda - Lbs. + 1000
SECTION A - Selected Power Plants Located Within the State of Ma																						
Morgantown	1	1972	2070		-	-	291.9		42	0	500.0	0	0	0	0		-	-	155.6		0	42.0
Wagner	2	1972	1096		39.8	20.0	59.8		0	0	412.0	0	0	0	0		43.1	5.3	48.4		0	0
Chalk Point	3	1972	1409		-	-	230.0		0	0	748.3	0	0	0	0		-	-	102.0		0	829.4
Dickerson	4	1972	679		-	-	116.0		0	0	78.0	1.02	0	0	0		-	-	26.0		0	153.1
Crane, C. P.	5	1972	347		68.3	0.0	68.3		0	0	0	0	0	0	0		8.3	4.7	13.0		0	.0012
Riverside	6	1972	573		71.4	7.0	78.4		0	0	144.0	0	0	0	0		11.6	2.3	13.9		0	12.0
Vienna	7	1972	220		10.0	6.0	16.0		-	-	-	-	-	-	-		6.0	3.0	9.0		1.0	7.4
Westport	8	1972	563		28.2	7.4	35.6		0	0	152.0	0	0	0	0		9.4	0.3	9.7		0	0
Gould St.	9	1972	237		39.2	7.0	46.2		0	0	144.0	0	0	0	0		6.0	1.5	7.5		0	.0024
H. T. Smith	10	1972	166		1.5	0.0	1.5		0	0	0	0	0	0	0		6.0	3.0	9.0		0.0114	0
SECTION B - Selected Power Plants Located in the Maryland R																						
Mt. Storm	11	1972	1120		136.7	2.2	138.9		1.7	0	0	0	0	9.38	0		27.0	10.0	37.0		16.8	32.3
Herring Pt.	12	1972	450		-	-	264.2		169	22	86.0	1.0	.02	0	0		-	-	129.0		0.004	0
Potomac River	13	1972	697		-	-	38.2		62	70	150.0	0	0	0	0		-	-	36.3		6.47	61.68
Possum Pt.	14	1972	466		1.7	0.2	21.9		0	0	0	0	0	0	600.0		72.1	7.5	79.6		0.3	1.4
Buzzard Pt.	15	1972	880		83.0	0.6	90.6		0	0	9.0	0	0	0	0		19.0	1.44	20.44		2.04	8.0

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FORMATION SHEET" ON COST OF OPERATION AND MAINTENANCE
DDITIONS TO BOILER AND COOLING WATER SYSTEMS

CTION A - Selected Power Plants Located Within the State of Maryland

Calcium Hypochlorite - lbs. ÷ 1000	BOILER WATER SYSTEM	MAKE-UP AND BLOWDOWN			CHEMICALS ADDED TO BOILER WATER	Phosphate - lbs. ÷ 1000	Caustic Soda - lbs. ÷ 1000	Hydrazine gal.	Lime - lbs. ÷ 1000	Sulfuric Acid - gals. ÷ 1000	Ammonia - gals. ÷ 100	Ammonium Hydroxide (28%) - lbs. ÷ 1000	Alum - lbs. ÷ 1000	Sulfite lbs. ÷ 1000	Anti-Foam - lbs.	Sodium Sulfite - lbs. ÷ 1000	Sodium Hydroxide - lbs.	Trisodium Phosphate - lbs.	Soda Ash - lbs. ÷ 1000	Chlorine - lbs.	Sodium Chloride - lbs.	Neutralizing Amine - gal.	Hydrazine - lbs.
		Annual Operation and Maintenance Cost ÷ $1000	Annual Chemical Additive - Cost ÷ $1000	Total Annual Cost ÷ $1000																			
0		-	-	155.6		1	42.0	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		43.1	5.3	48.4		0	0	0	0	0	0	22.7	0	0	0	0	0	0	0	0	0	0	0
0		-	-	102.0		0	829.4	330	40.0	38.0	14	0	36.6	0	0	0	0	0	0	0	0	0	0
0		-	-	35.0		0	163.1	434	1.88	12.0	105	0	60.8	0	0	0	0	0	0	0	0	0	0
0		8.3	4.7	13.0		0	.3012	826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		11.6	2.3	13.9		0	12.0	580	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-		6.0	3.0	9.0		1.0	7.4	91	185.0	0	0	0	0.6	0	0	5.1	0	0	0	200	1.5	4.0	0
0		9.4	0.3	9.7		0	0	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		6.0	1.5	7.5		0	.0034	330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		6.0	3.0	9.0		0.0114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SECTION B - Selected Power Plants Located in the Maryland Region																							
0		7.0	18.0	25.0		16.2	92.3	0	426.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		-	-	129.0		0.304	0	325	0	0.027	0	0	0	0	0	0	0	0	0	0	0	0	0
0		-	-	26.0		7.47	68.68	95	0	130.0	0	0	0	0	0	0	0	0	0	0	0	0	0
600.0		78.1	7.5	79.6		0.5	1.4	0	0	1.65	0	0	0	1.3	110	700	800	200	2.5	0	0	0	110
0		19.0	1.44	20.44		2.34	5.0	210	0	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 5 - "POWER PLANT INFORMATION SHEET" AND SUPPLEMENTARY DATA

SECTION A - Selected Power Plants Located Within the State of Maryland

POWER PLANT - OPERATING UTILITY	Reference Number	Reported Year	LOCATION	Latitude °N	Longitude °W	Name of the Nearest City or Community	Distance from Nearest Community - Miles	Population of Nearest Community	NOISE	Noise Level of the Power Plant	Frequency of Noise Complaints	AUXILIARY SYSTEMS	Plants Cleaning Air Heaters	Air Heater Cleaning Method	Method of Disposing of Air Heater Cleaning Water	BOILER MAKE-UP WATER SYSTEM	Plants Employing Demineralizers in Make-up Treatment	Plants Employing Cation-Anion Exchanger in Make-up Treatment	Plants Employing Decarbonation in Make-up Water Treatment	Plants Which Provide for Boiler Water Recovery From Blowdown	CHEMICAL DISPOSAL	Plant Employs Disposal Facilities	Public Owners
Morgantown (PEPCO)	1	1972		38.4	77.0	Clifton, Md.	1.0	25		L	R		X	W	NI		X	X	-	X		X	
Wagner (BG&E)	2	1972		39.2	76.5	Glen Burnie, Md.	.3	30		L	O		X	W	ST		X	X	-	X			X
Chalk Point (PEPCO)	3	1972		38.5	76.7	Eagle Harbor, Md.	1.5	40		L	R		X	W	NI		X	X	-	X		X	
Dickerson (PEPCO)	4	1972		39.2	77.7	Dickerson, Md.	1.0	120		L	R		X	W	NI		X	X	-	X		X	
Crane, C. P. (BG&E)	5	1972		39.4	76.3	Baltimore, Md.	.3	30		L	O		X	W	ST		-	X	-	X			X
Riverside (BG&E)	6	1972		38.2	76.5	Dundalk, Md.	.25	NI		L	O		X	W	ST		-	X	-	X			X
Vienna (DELMARVA)	7	1972		38.4	75.9	Vienna, Md.	.25	400		M	O		X	W	FSP		X	X	X	-			X
Westport (BG&E)	8	1972		39.3	76.6	Baltimore, Md.	.25	3000		L	O		X	W	SB		X	X	-	X			X
Gould St. (BG&E)	9	1972		39.3	76.6	Baltimore, Md.	.1	NI		L	O		X	W	SB		X	X	-	X			X
R. P. Smith (APSCO)	10	1972		39.6	77.8	Williamsport, Md.	.1	2000		L	1/yr		X	W	ST		X	X	-	X			X
SECTION B - Selected Power Plants Located in the Maryland Region																							
Mt. Storm (VEPCO)	11	1972		NI	NI	Mt. Storm, Va.	NI	NI		NI	NI		NI	NI	NI		NI	NI	NI	NI		Y	
Benning Road (PEPCO)	12	1972		NI	NI	Washington, D.C.	NI	NI		NI	NI		NI	NI	NI		NI	NI	NI	NI			X
Potomac River (PEPCO)	13	1972		NI	NI	Alexandria, Va.	.1	NI		NI	NI		NI	NI	NI		NI	NI	NI	NI			X
Possum Point (VEPCO)	14	1972		38.6	77.3	Dumfries, Va.	NI	NI		NI	NI		NI	NI	NI		NI	NI	NI	NI		NI	NI
Buzzard Point (PEPCO)	15	1972		NI	NI	Washington, D.C.	NI	NI		NI	NI		NI	NI	NI		NI	NI	NI	NI			X

KEY: NI = No Information

Noise: L = Low
R = Barely
M = Medium

Auxiliary Systems: ST = Settling Pond
FSP = Fly Ash Settling Pond
SB = Settling Basin
W = Water

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